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Malware mimics for network security assessment

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MALWARE MIMICS FOR NETWORK SECURITY ASSESSMENT

by

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March 2011

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For computer network infiltration and defense training within the Department of Defense, the use of Red Teams results in the most effective, realistic, and comprehensive training for network administrators. Our thesis is meant to mimic that highly trained adversary. We developed a framework that would exist in that operational network, that mimics the actions of that adversary or malware, that creates observable behaviors, and that is fully controllable and configurable.

The framework is based upon a client-server relationship. The server is a Java multi-threaded server that issues commands to the Java client software on all of the hosts of the operational network. Our thesis proved that commands could be sent to those clients to generate scanning behavior that was observable on the network, that the clients would generate or cease their behavior within five seconds of the issuance of the command, and that the clients would return to a failsafe state if communication with the command and control server was lost.

The framework that was created can be expanded to control more than twenty hosts. Furthermore, the software is extensible so that additional modules can be created for the client software to generate additional and more complex malware mimic behaviors.

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MALWARE MIMICS FOR NETWORK SECURITY ASSESSMENT

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LIST OF ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
CDX	Computer Defense Exercise
COMPTUEX	Composite Training Unit Exercise
CSTT	Combat Systems Training Team
DHCP	Dynamic Host Configuration Protocol
DISA	Defense Information Systems Agency
DoD	Department of Defense
DNS	Domain Name System
GUI	Graphical User Interface
HTTP	Hyper Text Transfer Protocol
KBps	Kilobytes Per Second
ICMP	Internet Control Message Protocol
IP	Internet Protocol
IRC	Internet Relay Chat
MBps	Megabytes Per Second
MM-Client	Malware Mimic Client
MM-Server	Malware Mimic Command and Control Server
NSA	National Security Agency

RaD-X	Rapid Experience Builder
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
VM	Virtual Machine
VBS	Visual Basic Script

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I. INTRODUCTION

Department of Defense (DoD) use of information systems connected by networks continues to expand, as it arguably does for every enterprise level organization in the world today. The threats on the Internet—viruses, botnets, hackers and the like—form the basis for enormous vulnerability, both to the machines of the networks, and to the Department of Defense mission that those machines support: protecting the security of the United States of America.

Network administrators perform a vital role in both administering and protecting our networks. They carry out the myriad tasks essential to the function of the network, ranging from the routine to the tremendously complex—configuring the host machines, the network hardware, the firewalls, interfacing with the system users—the list continues ad infinitum. Network administrators form the bulwark of our defense, which is referred to as “Information Assurance.”

The traditionally accepted “threat equation” states that risk is equal to threats multiplied by vulnerabilities—mitigated only by safeguards [1]. Since the safeguards of DoD networks, indeed any network, is most fundamentally influenced by the skill of its administrators, the primary mitigation of risk to DoD networks (indeed the DoD on the whole and ipso facto, the security of the entire nation) rests on the quality of training provided to our network administrators. When we consider that the threat to our networks are ever increasing, as is our usage of them and the concomitant increase in vulnerability, it becomes that

much more imperative that we provide the best and most effective training possible to our network administrators.

A. TRAINING NETWORK ADMINISTRATORS

DoD training of its network administrators relies on a wide variety of different methods. Classroom instruction is standard, as are mentors performing on-the-job training. Instructed laboratory environments are also commonplace. Still, the most significant training of DoD network administrators in the area of information assurance is performed by the use of red teams. These red teams are composed of highly-trained, specifically-tasked personnel that act as adversaries in order to test the networks and their administrators by emulating the threats that the administrators currently face.

B. SHORTCOMINGS OF THAT APPROACH

While classroom training of network administrators is essential, it is often considered unsatisfactory for the sorts of robust evaluations required in the military environment. Laboratory training can be more robust, but the training does not evaluate the strengths and weaknesses of the actual network of the organization. The red team approach is superior in both these areas; the training is both robust, and often performed on the operational network of the organization. Still, the DoD red teams that perform this training are not an unlimited asset. They consist of personnel with specialized training requirements, limited funding and operational tempo, etc. Reliance on red teams, thus, restricts the amount of training available to DoD

network administrators. This in turn impacts DoD networks on the whole, and is therefore a matter of national security.

C. OBJECTIVES

Our objective is to design a network training tool to help train administrators—one that can integrate the network evaluation into the highly complex training events typical of U.S. military training exercises. Towards this, we seek to construct a system with the following characteristics:

- The system must be safe enough for use on the operational network, and not constrained for use in the laboratory. Towards this, it must be inherently benign, externally controllable, and include a tested failsafe condition for rapid neutralization and/or retraction (rollback) from the impacted network.
- The system must emulate threat *behaviors* rather than duplicating the threats themselves, i.e., the system must be constructed of malware mimics, not actual malware.
- The system must be distributed, allowing the trainer to be geographically distinct from the network and the network administrators undergoing training.

D. ORGANIZATION

Chapter I provides a brief treatment of the motivation for this thesis: mainly, the defense of the United States

through improved training for the administrators of DoD networks. This goal we propose achieving through the use of a distributed software system.

Chapter II gives a more formal definition of red teams, as well as usage examples of red teams in DoD environment. Chapter II also gives a brief overview of the current threats to networks and enumerates some of their behaviors.

Chapter III covers the design considerations of our proposed software solution. We formally define the interested parties in training, as well as the training objective, and give an example of how the proposed system could be used in an actual training exercise. We give further treatment of our stakeholders in training, and specifics on what behaviors might be desired that a software solution perform.

Chapter IV has discussion of the actual software implementation of the system, to include the Graphical User Interface (GUI). It also discusses the complex test-bed on which we tested our implementation.

Chapter V presents results from our testing of the system, to include graphical representation of system performance. It shows that the software system we have implemented does indeed generate externally observable network behaviors that are remotely controllable.

Chapter VI is the summary of the thesis, with conclusions regarding the outcome. It also enumerates future work that could be done on this project, to include some of the areas that will require more refinement before the system is ready for a production environment.

II. BACKGROUND

This chapter gives more specific treatment of red teams used in a DoD setting, to include employment. Additionally, some of the threat signatures and behaviors used by red teams are discussed, to include bots, worms, and viruses.

A. RED TEAM

Red teams are “specially selected groups designed to anticipate and simulate the decision-making and behaviors of potential adversaries.” [2] The red team forces an organization to examine itself critically. No organization is perfect, no weapon system is perfect, and no idea is perfect. The red team examines whatever it is that needs to be evaluated, uncovers its flaws, and finds potential weaknesses that can be exploited. Sun Tzu said, “If you know your enemy and know yourself you need not fear the results of a hundred battles.” [3] Complete knowledge of the enemy may be impossible, but through the use of red teams, a more thorough knowledge can definitely be gained about one’s own organization.

Red teams are used in all aspects of military planning. They are used at the tactical level in mock battles using infantry, mechanized, and/or aerial units acting as a real, opposing, red force. The two-week, high intensity, Red Flag training exercise held at Nellis Air Force Base (AFB), Nevada (on occasion at Eielson AFB, Alaska) was created to simulate realistic combat missions against a credible and live opposing force. Red teams, typically led by staff Intelligence Officers, are used in staff planning of future

maneuvers to foresee possible reactions or resultant movements of the enemy. They are utilized in the creation of new weapons or new national or military guidance publications, such as the National Security Strategy, Joint Strategy Review, and the Maritime Strategy. One example was the led by the Naval War College. Most notably, the Global War Games from 1984-1988 resulted in many significant conclusions that helped to define the Maritime Strategy at that time [4]. By having red team think tanks and war gaming scenarios, the actions of forecasted adversaries can be identified. This information could then sway the future actions of the entire DoD.

From the aspect of cyber-security, red teams are vital in the training of the government and military network operators. The term operators can be as broad as the entire staff, which will include managers and officers, administrators, engineers, help desk, and response technicians. The term operators in this thesis will limit its scope to the administrators, help desk personnel, and technicians.

B. RED TEAM DURING CYBER DEFENSE EXERCISE (CDX)

One of the two red team examples will come from the annual Cyber Defense Exercise (CDX) that is held between the United States Service Academies, other military academic schools (Air Force Institute of Technology and Naval Postgraduate School), and on occasion, other nations' military schools (e.g., in 2010, the Royal Military College of Canada was part of the competition). The tenth annual CDX sponsored by the National Security Agency (NSA) was in 2010 [5].

In the CDX, it is each school's mission to design a network from scratch, build it in its entirety, fortify it and then defend it for an entire week against external and internal attack. The network must meet a certain baseline such as providing a Web service, domain name service, active directory, e-mail, bulletin board, and more. The students must research what are the most effective and secure operating systems to use. Then, the applications and services must be identified, installed, and properly configured. These computers and services must then be joined to a network which is then linked into the entire game network via a Virtual Private Network connection which logically removes the game network from the rest of the internet. The NSA red team is situated in its own network with access to the entire game network where it can launch attacks against all of the competing schools. In the 2010 competition, the red team had an agent on the inside of each school's network, along with a cluster of five improperly configured computers. The agent, acting the part of the "ignorant user" could be persuaded to visit malicious websites and click on dubious e-mail attachments.

Getting the entire exercise network researched, built, and operational takes a great deal of effort by students. Further efforts are required to harden the computers, operating systems, services, and the entire network. Getting the entire network operational is merely the ante to compete in the CDX. For the participants, the real work and concomitant training value comes from the competition week when the NSA red team begins their attacks.

As delineated in the Certified Ethical Hacking Manual, there are five phases in which an intruder advances the attack [6]. The red team followed these typical five phases: reconnaissance, scanning, gaining access, maintaining access, and covering their tracks. Some steps were shortened (reconnaissance, since some information is already known) or skipped (covering of tracks, since the students need to identify what was compromised). This is done so that the students of the competing schools can experience what it is like to be scanned, infiltrated, and exploited. The detection of the infiltration or the witnessing of unintended actions must be noticed, steps taken to neutralize the problem, corrective actions taken to restore impacted systems, and further research and steps taken to prevent that problem from happening again. The red team would do their best to infiltrate as many systems as possible and leave their mark for the schools to find.

The red team was limited in what they were allowed to use in their attacks. Common hacking software suites, e.g., Backtrack and Metasploit, were utilized along with a host of other easily available tools that anyone with access to hacker sites on the internet could obtain. Current exploits and vulnerabilities could also be used if they were present on the networks. This encouraged the competing schools to review the current literature and download and install the current applicable patches for their systems. The red teams were not allowed to generate their own malicious code or exploits.

The red team presented a live, thinking opponent to all of the competing schools. Automated tools and other

software were utilized, but the red team members took the data that was returned and formulated strategies of what to attack next. The intelligent enemy could probe further, find out what is installed, and run attacks against known vulnerabilities of the running software or installed operating systems. Furthermore, the inside red team agent was another vector of attack. These two facets taught the students to look for attacks from outside and within, how to effectively place and use sensors, to research and constantly update their systems, and if anything was breached, how to investigate, limit the extent of the damage, and restore the system to operation with the vulnerability removed.

The only negative aspect of this exercise is that it is done on an exercise network. As mentioned previously, the point of the exercise is to build and defend a network. Therefore, all of the decisions were made with security as the top priority. This is not true for every organization and every network. Having this exercise done on a true, operational network, with all of the requirements and needs of the user-base met, and with hundreds or thousands of constant users, would make this exercise even more realistic.

C. RED TEAM DURING COMPOSITE TRAINING UNIT EXERCISE

An example of an exercise that does use the operational network is the Composite Training Unit Exercise (COMPTUEX). It is the culminating exercise for the qualification of a strike group. A strike group of usually five to seven ships spends nearly a year in the predeployment workup cycle and upon successful conclusion of COMPTUEX, the battle group is

assessed to determine its readiness for deployment and for battle. The COMPTUEX is an intense exercise that is developed to stress the entire group: the staff, the ship's officers, the ship's crew, the Marines, (if embarked), the joint component, and the Air Wing, to name a few.

COMPTUEX is the time when the onboard computer networks are attacked by the red team from the Navy Cyber Defense Operational Center. As previously mentioned, COMPTUEX is the final exercise for the strike group. The cyber attacks are only a small portion of all the attacks that will be directed toward these ships. The ships have multiple objectives to complete every day. Some events are specific to one ship, others to some subset or all of the ships. These events affect every person onboard. With the increase in workload, the computer networks, communication systems, and combat systems are heavily utilized to accomplish the many missions set forth by the examiners. It is during this tumultuous time that the red team also attacks these vital networks.

All of the events of COMPTUEX are scripted by the evaluators at the Center for Surface Force Training Atlantic or Tactical Training Group Pacific. Since they are scripted and all actions must be graded, there are breaks given so that vital systems or groups that must be graded will have the tools normally available to them to accomplish their task. Therefore, the red team will not usually target vital systems during the war-fighting phases of the training. The red team will usually attack during the quieter times of the whole exercise. This is difficult for the network administrators and technicians: following manning their

battle stations during simulated combat operations, they must then man their normal shipboard watch stations and continue defending from attacks by the red team. Purposefully, some of the attacks on the computer networks and communication systems are linked to the battle. There are specific training objectives designed to take down vital communication channels during attacks or evolutions so that the ships and watch teams can be evaluated on their response. This is to allow the assessment of such questions as: “Can the ship fight without their normal complement of communication options?”

In this context, the red team of COMPTUEX performs similar functions to the red team of the CDX. The red team attempts to scan the system, breach it, and then exploit it. Since this training is done on an operational network, certain behaviors are desired without the exact malware being introduced to the network. Therefore, the red team simulates the effects of some of the more nefarious attacks. The mission of the red team is to test the vigilance of the network administrators, technicians and, to an extent, the users of that network. Some of the attacks are only detectable by the administrators, and then only by reviewing the logs of the firewall, intrusion detection systems, and other sensors and services. Some of the attacks the users will see in malicious emails, odd things happening on their work computers, or even strange printouts on networked printers. The attacks are varied and thorough, testing all equipment, sensors, and people.

By having a red team attack an operational network, the training and evaluation are much more realistic. The actual

network administrators, technicians, help desk, and users are tested on the computers and equipment they use every day. This is the environment with which they are most comfortable. More importantly, these are the networks that will be used prior to and during the battle. Upon completion of the associated training and evaluations, the IT professionals on the ship now know the strengths and weaknesses of their own network. They know how to use their sensors and know what the sensors can and cannot reveal. Also, they may find that their network has some derived vulnerabilities due to the other systems with which it must interface. These are the residual risks that exist within all organizations.

The major downside to the training is that the full repertoire of attacks may not have been used because it is an operational network. The risk of corrupting or destroying the operational network could cripple the ship for days, weeks, or more depending on the attack. Such cases would be detrimental to the strike group readiness, likely preventing the on-time deployment of the strike group (COMPTUEX is usually immediately prior to the end of the workup cycle). Therefore, attacks of such intensity must either be avoided or simulated to some extent. The red team may not use them, but a true adversary would likely have no restrictions on what is or is not allowed.

D. A RED TEAM APPROACH USING RAD-X

An example of an interesting approach using red-team methodologies is the Defense Information Systems Agency's (DISA) use of the Rapid Experience Builder (RaD-X) training tool. RaD-X is essentially a portable network training

laboratory, isolated from the operational network and the Internet, allowing for its use as a “sandbox” for network administrator students to observe network exploits as they occur. With this tool, users can observe many of the threats discussed below—worms, botnets, viruses and the like—by use and analysis of intrusion detection and intrusion prevention systems organic to the system. RaD-X includes instructional courseware and formal laboratory exercises that complement the training the students receive while utilizing the laboratory network. Though portable, the footprint is significant: the system includes a large number of laptop computers and concomitant network hardware, as it is a self-contained training network [7].

E. RED TEAM EXPERIENCE

Exercises verses a red team is the pinnacle of a unit’s training. It is utilized in the capstone evaluation of this country’s deploying forces. The red team provides training that is as realistic as possible. It can produce an experience like no other.

As mentioned in the previous sections, the red team can attack from a multitude of vectors. Only a small subset of the attacks that the red team utilizes will be examined. The attacks that are examined are some of the most dangerous and disruptive to network security today.

F. MALWARE

A computer is a tool that executes instructions, or programs, at a very rapid pace. For the most part, a benign program does productive work, safely interacting with the

components of computer, such as the processor, the files on the hard drive, and other processes and data in memory. Malicious programs perform work or actions that the user does not want and ends with results that are insulting, frustrating, and/or damaging. Spam e-mail fits into all of those categories. Virus logic bombs that destroy critical files are incredibly damaging. Denial of Service attacks on e-commerce sites can be frustrating for the customer and potentially damaging for the business, normally resulting in lost business and revenue. Root-kits that allow unauthorized access to other people's or organization's computer resources are a significant security risk, and usually causing some form of loss or damage.

"Malware" is the overarching term used to describe the programs that force the computer to execute these misbehaving tasks. The types of malware that will be considered herein are: worms, botnets and viruses.

1. Worms

A worm is stand-alone malicious code that propagates across the hosts of a network, with or without human assistance—no interaction on the part of a user is required. According to Gu (et al.), there are three characteristics of an Internet worm:

- Internet worms generate a substantial volume of identical or similar traffic. This can be detected by passive listening on the network, as performed by protocol analyzers like Wireshark or Intrusion Detection Systems like Snort.

- They use random scanning to probe for vulnerable hosts, which can also be detected by those passive listeners.
- Compromised hosts exhibit predictable signatures: an uninfected host would have “normal” traffic, but when infected, the host begins random scanning looking for other vulnerable hosts on the network.

In addition to propagating itself by finding additional vulnerable hosts, worms typically have some other malicious function. It may direct users to certain websites or it may collect information from the infected host and report it back to some central computer. It could also be malicious and try to destroy key files on the host computer [8].

Some examples of worms include the Morris worm (1988) [9], the first known instance of a worm, as well as the Nimda and the Code Red worms [10].

2. Botnets

Bots and networks of bots (“botnets”) are emerging as the most significant threat facing online ecosystems and computing assets [11]. Like viruses and worms, a bot is a self-propagating application (code) that infects vulnerable hosts through exploit activities in order to expand the reach of the Bot network [11]. Bots can use worms or other bots to propagate to other computers on the network.

Bots can be distinguished from viruses and worms by their command and control characteristic: bots will normally include facilities that allow for control by some sort of Command and Control structure, be it a single server or some

type of distributed system. Since bots can be controlled by a single entity, they can be remotely directed towards a single purpose. A typical use for a bot is a Distributed Denial of Service (DDOS) attack, where a massive number of bots can coordinate their traffic in order to overwhelm a network server [11].

Bot behaviors include those of worms outlined above, with the addition of command and control traffic that rides within different protocols: commonly Hyper Text Transfer Protocol (HTTP) and Internet Relay Chat (IRC). In actual bots, this traffic may or may not be encrypted. Detection of bots through passive packet monitoring (as above—with protocol analysis by tools such as Snort or Wireshark) of data streams can be useful, as bots will often exhibit typical signatures or behaviors. Like worms, the scanning behaviors used for propagation can also be detected passively and the results used for bot (and worm) identification [11]. Bots will often remain hidden until they receive instruction from the command and control server to execute some action, which is typically a denial of service attack as described above [12],[13].

Perhaps the most widely known example of a bot is “Conficker,” which is still active at the time of this writing. One estimate of Conficker held it responsible for 8.9 million infections, and it appeared in a variety of different networks, including those of the German and British Armed Forces [14].

3. Viruses

In Peter Czor's The Art of Virus Research and Defense, he defines a computer virus as "…code that recursively replicates a possibly evolved copy of itself. Viruses infect a host file or system area, or they simply modify a reference to such objects to take control and then multiply again to form new generations." [15]

Viruses can be classified by many categories. These include what computer architectures they target, such as processor types or operating systems; file systems and file formats; interpreted environments such as scripts (PHP, Jscript, Batch and Shell scripts) and macros; and more. They can also be classified as to how they infect, such as boot records, files, and in-memory. They could be classified as to their defensive mechanisms, like tunneling, armored, retroviruses, morphing and encrypting. Finally, they could be classified according to their payload, whether it is intended to be benign and non-destructive, destructive, data-stealing, or denial of service.

Since all viruses are code and that code must reside somewhere on the host, the signature-based virus scanner periodically searches for those classic signatures on a system. Only new viruses or emerging variants of existing viruses will cause the scanner to fail to match the stored signatures and claim that the code is safe.

A canonical example of a virus is the "Anna Kournikova" virus. Although it did not have a malicious payload, it made its way through a bulletin board posting, through mass-mailing capability, and social engineering (enticing people with a new picture of Anna Kournikova) to spread itself

around the world. The file was a visual basic script: AnnaKournikova.jpg.vbs. It duped the user into executing the script, e-mailing itself with the VBS attachment to everyone in the user's e-mail address book. Its payload was nothing except spam e-mails that quickly spanned the world [16].

G. SUMMARY

In this chapter, we discussed the usage of red teams used in a DoD setting, and examples of exercises in which they are employed. We also discussed some of the threat signatures and behaviors used by red teams, including bots, worms, and viruses. In the following chapter, we assert that DoD use of red teams constrains how we train, and propose a information system solution.

III. DESIGN CONSIDERATIONS

In this chapter, we make a few definitions, namely those of the "training objective" that we are training to, the "trainees" that are receiving the training, the "trainers" that train them, and the "safety observers" that observe all of the above. We scope our discussion by a defining the training "environment," as well as identify the problems with the DoD's current approach to network training. We proposed an information systems solution to those problems and give a detailed example scenario of its use. We conclude the chapter with more detailed discussion of the above elements.

A. THE TRAINING OBJECTIVE

In order to simplify discussion, we make an initial definition: the training objective. The training objective is the skill or behavior that we wish to reinforce. We make no comment on the size, complexity, or specifics of the training objective—they can range from the simple to the very complex, e.g., from "pull the trigger" to "win the war." We limit our scope of training objectives to the specific behaviors that result from trainee interaction with malware/mal-behavior and its accompanying effects. We also assume that training objectives correspond to specific threats which have specific behaviors. Further, we do not discuss any specific training methodology or algorithm, as it is beyond the scope of this thesis. Below, we include an example training scenario, with its training objective.

In order to discuss any training tool, we must also identify the stakeholders. Towards this, we propose three generalized parties typical in a military training environment and indeed, most training environments: the Trainee, the Trainer, and the Safety Observer.

B. THE INTERESTED PARTIES IN TRAINING

1. The Trainee

The “trainee” is a person or group of persons in the organization that we wish to be trained to the training objective. Specific examples could include network operations personnel, or perhaps even further up the stack of decision making, e.g., network managers.

2. The Trainer

The second participant in training is the “trainer.” The trainer is the person or organization that presents specific scenarios of behaviors to the trainee in order to evaluate the trainee’s performance vis-à-vis the training objective. Typical examples of trainers in military networks include “red teams” (who simulate the Tactic, Techniques, and Procedures (TTP) of adversaries) as well as less formalized trainers, e.g., the more experienced network operator training the less experienced. In “high school” parlance, the trainee is the student, and the trainer is the teacher, though this relationship is not exclusive, i.e., the trainer may or may not be the one giving the instruction, but the trainer is limited to testing the skill of the trainee.

3. The Safety Observer

The third participant in training is the safety observer. In many training scenarios, we need to define a party separate from the trainer and the trainee that is responsible for maintaining oversight of the conduct of the training. For example, during safety critical training, there is often a safety observer, whose scope of attention exceeds that of the training activities to include the impact of the training on the organization as a whole. In "military training" parlance, this could be members of a so-called "White Cell." Note that circumstance will sometimes dictate that either the trainer or trainee fill this role, e.g., in those training scenarios where the risk of training does not warrant the use of a separate party. A specific example would be that of a senior network administrator tutoring a junior administrator while utilizing an isolated (non-networked) host. An example of a needed safety observer would be training of such complexity that the trainer and trainee could not effectively train while simultaneously ensuring their training would not impact the safety of the organization, e.g., a large scale training scenario involving integrated operations from multiple major departments. Network training on an aircraft carrier network during flight operations and engineering drills would be an example of this.

C. THE TRAINING ENVIRONMENT

Now that we have discussed the interested parties in our discussion of training, we must discuss the training environment. For the purpose of this thesis, we limit

ourselves to training the administrators of military networks. That said, military networks vary enormously in terms of size and complexity, ranging from the completely isolated host in the training laboratory to the entire Global Information Grid, the military's global communications backbone comprising 15,000 networks and seven million computing devices across hundreds of installations in dozens of countries [17]. Note that DoD networks also span different classification levels, though we will not treat the requirements contained in these differences. Military networks include those of an administrative nature, e.g., training laboratories for network personnel, as well as networks of an operational nature, where lives and mission success literally depend on their effective utilization.

The differences between these networks also indicate, ipso facto, greatly varying network infrastructure and topologies. Some DoD networks have network firewalls, some have multiple tiers of them, and some have none. Some networks are completely hidden inside Network Address Translation realms, and some are outward facing onto the global Internet. Some networks are connected by high bandwidth fiber-optic cable, while others are connected by low-speed, high-latency satellite connections that offer slightly better connectivity than low-speed telephone modems.

D. HOW WE CURRENTLY TRAIN

The treatment Aland gives in the International Test and Evaluation Association Journal gives an excellent and timely

overview of the challenges faced by DoD leadership regarding Testing and Evaluation of DoD network Information Assurance, some of which are included below [18].

1. Dependence on Red Teams

One problem that the DoD faces with regards to training is that we depend heavily on red teams. Red teams are a resource heavily in demand, provided by agencies that are faced with increasingly austere fiscal environments. By use of this constrained resource, we limit the training options available. An exercise planner simply cannot count on a red team being available for every exercise.

2. Standardization

Given the complexity of military networks, it is not hard to imagine that maintaining uniformity in training throughout a global organization is a difficult task. Although the DoD continues efforts to centralize network training, there remain disparate organizations using disparate tools and methodologies. For example, it is not uncommon for a single unit to be trained by National Security Agency (NSA) Red and Blue Teams, for personnel to be serving as mentors in the same organization as the trainee, or for organizational training teams to exist at every echelon within an organization—all using a variety of different methods. For this reason, it is difficult to maintain standardization in training across the different networks in the DoD.

In addition to disparate organizations participating in the training, there are different organizations managing the

different networks as well. Each of these network management bodies imposes its own requirements on the trainers in order to minimize the impact of network training on the operations of the organization.

It is also possible for the organization to confine their network training to a laboratory environment, vice the operational network, in order to minimize the impact of the training on operations. A great example of this is the NSA's annual Computer Defense Exercise (CDX), discussed in Chapter II: a geographically distributed but logically isolated exercise network. The DoD keeps much of its training in the laboratory for good reason; one does not want to risk network behavior having negative effects on a unit's primary operational (non-network) mission. Robust network training, to a large degree, is considered too risky for operational units. Some training methodologies, e.g. the release of a worm along the lines of Morris (discussed in Chapter II), could have unpredictable results. Consider, for example, the trainer's use of a worm whose effects were intended to be limited to the unit under assessment, but instead spread over the entire organizational network.

Unfortunately, this deprives the operational units of the opportunity to observe how collateral network effects can affect the organization as a whole, e.g., seeing how the loss of a tertiary air traffic control information system due to a virus can affect the launching and recovery of aircraft. For this reason, it is imperative that network training not be limited to the laboratory, but instead be integrated into a holistic assessment of the unit.

E. AN INFORMATION SYSTEM SOLUTION

For these problems, we propose the development of a distributed, software-based training system that can be used by either simulated adversaries (such as red team) or trusted agents (such as blue team) to create scenarios and conditions to which a network management/defense team will need to react and resolve. This system will be composed of currently available software packages and/or "homegrown" (locally generated) packages with the desired functionality. It will include clients that function as "Malware Mimics," that is, software objects that intrinsically demonstrate externally observable attributes of the malware which it mimics, to include behaviors and possibly signatures, without putting the hosting network at risk. The Malware Mimic Client will be constructed in such a way as to depict a variety of these behaviors, with sufficient flexibility for additional behaviors to be "bolted-on" as they are developed later in the system's life, resulting in a sustainable evolution of the product. This Malware Mimic System must be inherently benign, externally controllable, and include a tested "failsafe" condition for rapid neutralization and/or retraction (rollback) from the impacted network. The tool should be scalable in order to depict the full range of malware characteristics, from low sophistication through high sophistication, and adjustable in real time.

Specifically, we propose that the system be composed of two types of software packages: Malware Mimic Clients (MM-Clients), and a central Malware Mimic Command and Control (MM-Server) Server. The Malware Mimic Clients will be

lightweight software packages that “ride” upon host operating systems of the information systems (workstations, etc) of the trainee organization. Each of these clients will be logically connected to a Malware Mimic Server, which will deliver commands to the Clients, both individually and in the aggregate. Malware Mimic Clients will be capable of generating the behaviors of the malware/mal-behavior that we wished to emulate.

For example, as discussed in Chapter II, a typical behavior in Internet worms is that they scan for adjacent vulnerable hosts. In this case, we wish only to mimic the behavior of the worm, not the worm itself. The MM-Client, when commanded by the MM-Server, could perform a port scan of adjacent hosts, just as if it was an actual worm. To the observer, the behaviors will be identical, exactly as if a worm was propagating across a network when in fact, only the behaviors of the preexisting MM-Clients, commanded by the MM-Server, will be propagating. In this manner, we greatly increase the training’s value (we duplicate the behavior of an Internet Worm on the network) without greatly increasing the risk to the network (we actually only duplicate the behaviors, not the malware itself). Additionally, by using this typical client/server architecture, we can take advantage of the network property of distribution. The trainer, operating the Mimic System, need not be collocated with the trainee of the network.

We can reduce the risk to the network even further. MM-Clients will have only narrow windows to perform their behaviors before having to reconfirm their commands with the MM-Server. This ensures that with a loss of network

connectivity, the clients do not continue “head-less,” i.e., operating independently of the trainer’s desires.

Furthermore, using the “two-key” analogy commonly employed by ballistic missile systems, we can insert an additional server on the local network which serves as a local “kill switch.” This second layer of “kill authority” will ensure that if emergent local conditions required an immediate halt to training that it could be commanded without the delay of notifying the trainer.

In this manner, we solve the problems identified above: namely that we create a distributed training system that can be consistently and systematically employed across a variety of networks, safe enough to use on an operational network, all the while delivering the same training value of reacting to actual malware used in isolated laboratory environments. We can increase training value without concomitant increase in risk.

As discussed, the proposed system will have the capability to command observable behaviors and signatures on remote hosts. Additionally, it will include the ability for the trainer to monitor remote system status, as well as halt or continue the execution of behaviors as warranted by the operational situation. The only interaction that the trainee will have with the system will be to observe behaviors and signatures generated by the system and react to them. Finally, we propose to include the capability for an observer local to the training to have the ability to halt the execution of behaviors as local circumstances warrant. All of these functions are summarized in Figure 1.

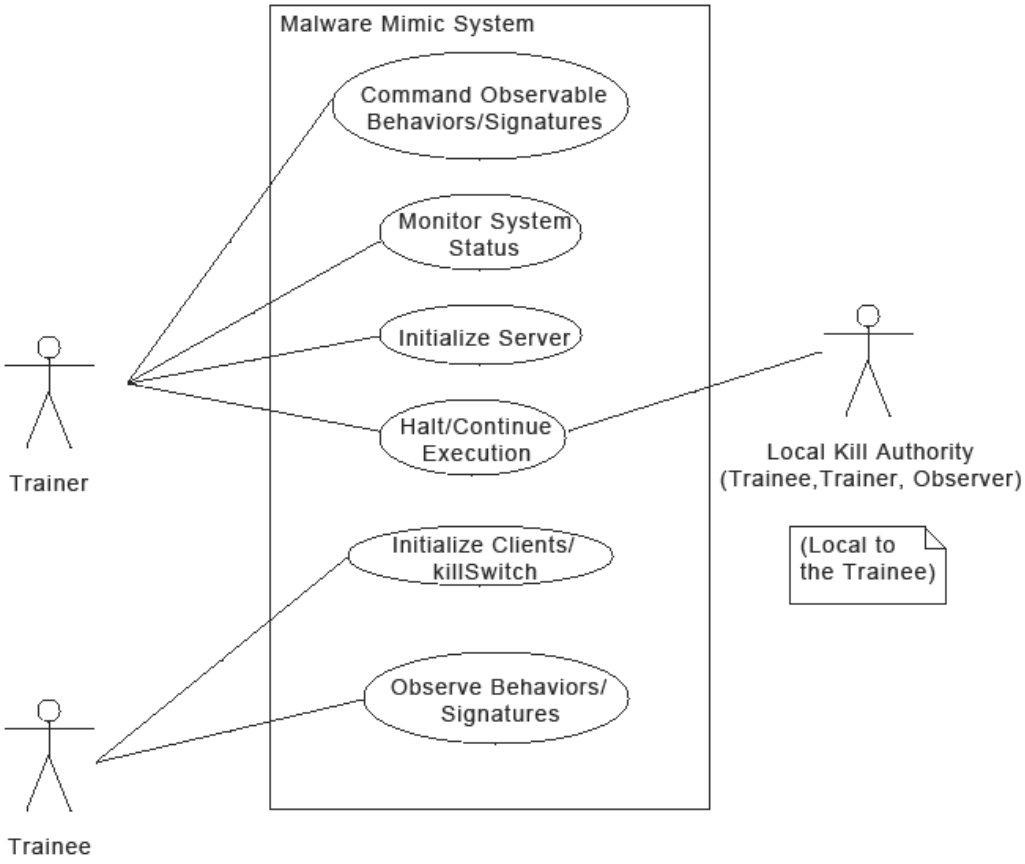


Figure 1. Proposed use case.

F. AN EXAMPLE TRAINING SCENARIO

Based on the proposed use case of our system, a more detailed training scenario may proceed as follows. This example assumes that the training would be formal and scripted in advance.

1. Pre-exercise (PRE-EX)

Prior to commencement of the exercise (COMEX), training objectives would be identified and tailored to the

particular trainee and training objective by interested parties. In this scenario, the trainee would be an organization: specifically, the network administrators of all the ships of a Navy Carrier Strike Group, underway off the coast of Hawaii, performing predeployment training exercises. The network environment would be an unclassified administrative network between ships of the Strike Group and connected to the Global Information Grid. The training objectives would be promulgated by the agency responsible for the exercise. Additionally, the training scenario would be synchronized with other typical predeployment training, such as the launching and recovery of aircraft, tactical maneuvering and communications of the ships, etc., which would be happening simultaneously with the network training. The training objective to be covered in this example would be that network administrators correctly identify a botnet propagating across their network, and report this information to the higher echelon of command in accordance with previously established procedures. The ships' Combat Systems Training Team (CSTT) would serve as the notional "white cell," i.e., safety observers for the exercise.

The Malware Mimic Client software would be installed on the participating hosts of the strike group network, distributed throughout the ships of the group via software push. These hosts would consist of the bulk of user workstations in the strike group. The software could be installed significantly ahead of time, as it would not affect the operation of the workstation prior to COMEX, remaining effectively dormant in a "sleep state" until the prescribed exercise time. Additionally, local to each ship of the group, a simple "kill server" would be initialized by

the CSTT members that could be used to terminate or freeze the exercise should local conditions warrant such action. Shortly prior to COMEX, all of the MM-Clients would establish a network link to the MM-Server co-located with the trainer, in this case a NSA red team physically located at Fort Meade, Maryland. The MM-Clients would still not have any effect on the user's workstation.

2. Commencement of Exercise (COMEX)

At the commencement of the exercise, the ships of the trainee (strike group) network, again, underway off the coast of Hawaii, would enter a Combat Systems Training Environment. This requires notification be passed throughout the ships of the group that ship systems were actively being used to support training and that actual systems casualties would be announced as such. CSTT members would take their posts and begin monitoring the system administrators (trainees). The red team (trainer) members, again located at their facility in Maryland, would log in to the MM-Server. They would select from their GUI menu the exercise trainee (our notional strike group). Per the exercise script, they would instantiate predefined software behaviors on the remote workstations of the strike group network. These particular modules would consist of behaviors to emulate a botnet propagating across the network. As such, network hosts would begin to scan the network in search of other "vulnerable" hosts in order to make network connections with them, at which point the scanned hosts would begin to scan the network as well. These scans would be accompanied by dramatic increases in host network output as the hosts simulate the sending of information off the

network to a notional botnet command and control server. In reality, this would be a coordinated, ever-growing amount of relatively benign scans or inert Internet Protocol (IP) packets which would cause an increase of network traffic.

The first indication of the emulated botnet on the trainee network would be a slowing of network traffic due to the congestion induced by the network scans and generated traffic. User logins would take longer due to the slow connection to the Active Directory server. Web traffic would slow down as well, as DNS queries are also delayed due to the congestion. Our trainees, busy with other duties assigned to them, would not yet notice the increase of network activity, the slowing of network traffic, or that the network monitoring systems of their network were indicating that the system was being scanned internally.

As the botnet behavior “propagates” across the hosts of the network, the network would continue to slow; e-mail traffic would now be affected as the volume of network traffic increased. Administrative work on the network workstations become affected as e-mail and chat traffic are affected. It can be expected that the help desk switchboard would “light-up” with complaints from users. Expectantly, the system administrators would be notified.

Upon inspection by the now alerted network administrators, the network would be determined to be under duress. Network management systems would show alerts related to the volume of traffic on the network; protocol analyzers would show unusual network connections between hosts of the network, and log files would show that systems

were being probed by internal scanning. The network trouble-call logs would be full of complaints by annoyed users.

The network administrators should correctly identify the problem with the network as a botnet-based attack. In accordance with established procedures, network administrators would notify the higher echelon that the network was infected by a botnet, who would in turn notify the NSA red team. Red team members would note that the training objective had been completed as the botnet had been identified and that the higher echelon had been properly notified. The CSTT would have Local Kill Authority. Once the training was complete, and in light of the complaints of the many users of the network, the CSTT would activate the "local kill" function of the system. The MM-Clients, no longer receiving the "go ahead" signal from the local kill server, would cease scanning and quickly revert to the pre-exercise inert state.

3. Post Exercise (POSTEX)

POSTEX (following the exercise), the MM-Clients would signal to the MM-Server, located in Maryland, that they had been stopped. The server operators (the red team) would note that the exercise had been halted locally, and confirm via out-of-band communication that the exercise had terminated normally. Trainers, assessors, and the trainees would then compile their individual notes on the exercise, and debrief the exercise via conference call once local conditions permitted.

G. CONTINUED DISCUSSION OF THE ENVIRONMENT

This was a both a simple and contrived example of the Malware Mimic's function, but it gives insight into a basic architecture from which to discuss, in further detail, the different features of the system. In the above example, we assume an unclassified, geographically remote, and tactical network. In reality, the Malware Mimic should scale well enough for administrators of any sized network to be trained, be it as small as a subset of a tactical network, or span multiple Autonomous Systems. The only limitation should be the management of the software packages that need to be pushed to the individual hosts of the trainee network, and limitations inherent in the architecture of the Command and Control structure of the Malware Mimic System.

In our example, we assumed an administrative network, but by use of both remote and local kill capability, as well as nearly instantaneous "roll-back" of the behaviors to a pre-exercise state, the Malware Mimic would be appropriate on networks where mission critical services are located. Note that in our example, the network behaviors are not performed on a network that is isolated in an air-gapped laboratory—the intent of the Malware Mimic is to get the training out of the lab and classroom, and into the actual operating environments of the trainees. Obviously, the more critical the systems (risk), the more care in the implementation of the emulated behaviors will have to be taken (controls/safeguards).

H. CONTINUED DISCUSSION OF THE TRAINER

Trainers on the system need not be geographically removed from the training environment. The power of the network allows the trainer to be located anywhere on the network, either remote or local. In our example, the trainer was in Maryland and the trainee was underway off the coast of Hawaii, but in reality, the location of the two parties could be any location linked together by the network.

Additionally, trainers need not be formalized, e.g., red team members. Assuming that a MM-Server is installed on the network and that a properly training operator of the server exists, training could be accomplished locally by the trainees themselves; that is, the "trainer" and "trainee" could be the same person or persons.

1. Expanded Modules

In our example, the threat was modeled as a botnet with the specific behavior of port scanning emulated. Modules could be created that generate the effects of any category of malware discussed in Chapter II. Any degree of complexity could be undertaken. In our example, only one stage of botnet propagation was emulated. Combinations of behaviors might be used to emulate specific threats. For example, the Malware Mimics on one host could be commanded to first scan for vulnerable hosts (behavior one), then "appear" on another host (behavior two), then the new host begin its scan (behavior three) and make a link with a remote host, ostensibly to pipe information offsite

(behavior four). This emulates in greater detail and complexity the lifecycle of a bot in a botnet.

We are not limited to the behaviors of bots. The Malware Mimics could just as easily be programmed to exhibit behaviors associated with a machine infected by a virus. Mimic-client host-machines could “pop-up” warning messages to users, asking them to contact system administrators to inform them of a mock “system infection.” Host workstations could generate virus signatures identifiable by virus scanners. Hosts offsite to the network could even be programmed to perform the same functions that a malicious hacker would perform on the trainee’s network.

I. CONTINUED DISCUSSION OF THE TRAINEE

In our example, our trainee was the network administration team of an entire Carrier Strike Group. Indeed, the “trainee” could be an individual, a team, or even an organization. Further, we need not limit ourselves to network administrators. The network effects generated by the Malware Mimic System, just as the effects of actual malware, can affect users, operators, managers, and decision makers further removed from the operation of a network. Their actions can be assessed using the Malware Mimic System, just as those of the network administrator. Consider the case involving the havoc created during flight operations by the loss of an entire mission critical information system; the response of system users or administrators in such a situation may have a profound impact on the mission as a whole. In this way, we can begin

to answer a question growing ever more important in modern combat operations: “How do the network operations impact the entire operational unit?”

In this chapter, we enumerated the participants in training, as well as scoped our training environment to that of a military network. We proposed an information systems approach to the problem and give a detailed example scenario of its use. In the following chapter, we give specifics on the construction of our solution, as well as the test bed used to evaluate its performance.

IV. IMPLEMENTATION AND TEST PLATFORM

A. BACKGROUND

This chapter will describe the creation of the MM-Server and MM-Clients. It will discuss the design features built into the software and how the implementation of the client-server relationship. In the first half, we will discuss the design of the modules that the MM-Clients will run, while the second half will discuss the creation of the test platform for this experiment. Finally, the experiment's goals will be defined and an explanation of how the experiment will be setup to accomplish those goals will be provided.

B. SERVERS AND BOTS

The architecture outlined in Chapter III was largely paralleled in our implementation, which includes a single command and control server (the MM-Server) that has a one-to-many cardinality relationship with our remote client nodes (the MM-Clients). For both the MM-Server and the MM-Client, we chose Java as the implementation language. The primary reason was portability; since we make no assumption on the physical architecture of the network, it was prudent to select a language that would run on a multitude of different platforms, to include Microsoft Windows and Linux.

The functions provided by our implementation also parallel the architecture outlined in Chapter III. A trainer gives commands via a user interface to the MM-Server, which then commands the individual remote MM-Clients

to perform an externally-observable, network behavior. The MM-Server commands that modules, consisting of the behaviors, on the remote MM-Clients be executed; MM-Clients receive the instruction to execute the module, and execute the preprogrammed function that performs the commanded behavior.

1. Server Construction

The MM-Server consists of six Java classes, including the data structure that maintains information on the client nodes of which the server is aware and the user interface. The MM-Server functions similarly to a Web server in that it spawns handlers to handle incoming connections from the MM-Clients. The server is multi-threaded to allow for multiple simultaneous Transport Control Protocol (TCP) connections and full-duplex communications with its MM-Clients.

The data structure utilized to track connections between the server and remote MM-Clients is a Java Synchronized Sorted Map. The Synchronized Sorted Map offers built-in handling for the multi-threaded environment, and its use simplified the coding requirements significantly, i.e., it inherently handled issues of thread synchronization. For larger (in terms of numbers of MM-Clients) implementations, a database, such as MySQL should be used, though it will come at the cost of added complexity.

In order to keep implementation as simple as possible (with an eye on scalability), the data structure maintains a traditional “mail box” model for MM-Client/Server communications; within the data structure, MM-Clients have

inboxes (orders) and status boxes. Inboxes are set only by the server; status boxes are first initialized by the server, and then written to exclusively by the MM-Client. In this manner, synchronization issues with multiple MM-Clients are avoided. The data structure is keyed uniquely by a concatenation of the host node's machine name and a node name given at invocation. The data structure also includes a field for explicitly declaring the exercise in which the node is participating, e.g., a specific strike group COMPTUEX.

2. Client Construction

On initialization, MM-Clients attempt to establish a TCP connection with the remote server whose socket pair address is declared in the invoking command-line parameters. If the remote server is not available, the MM-Client will continue to attempt contact every 10 seconds until the connection succeeds.

Once the connection is established, the MM-Client requests the contents of its "inbox" from the MM-Server, then calls the appropriate module based on the response. Modules contain preprogrammed sets of behaviors. Currently, there are three modules of behaviors. Module Zero is an instruction for the MM-Client to cease commanded behaviors, and to return to an idle state. In the idle state, the MM-Client continues to request its inbox contents from the MM-Sever at five-second intervals. Module One commands five icmp "pings" of the MM-Server. This module is used for connection troubleshooting. Module Two commands a "SYN scan" of 10 random ports of the MM-Server. This module is use to demonstrate the feasibility of a remotely-commanded,

externally observable, network behavior from the MM-Client. This behavior is intentionally modeled on the scans performed by the bots of a botnet, as discussed in Chapter II.

Module Two's complex scanning behavior is not native to Linux or to any of the Microsoft Operating Systems. For these scans, we utilized Salvatore Sanfilippo's "hping" software, available at www.hping.org under the GNU General Public License v2. Use of hping on Microsoft Windows platforms additionally requires the use of CACE Technology's WinPcap library (specifically, we used version 4.1.0.2001), whose license is currently available for viewing at www.winpcap.org/misc/copyright.htm. Additionally, we had problems using hping version 3 on XP; reverting to version 2 was required. This version is currently available at http://sourceforge.net/projects/sectools/.

Unfortunately, the use of hping clients on Linux hosts requires the use of raw sockets, which are not available without administrator privilege. This can be overcome by appending the command for hping to the sudoers list of the Linux client, e.g., %admin ALL = NOPASSWD: /sbin/hping3.

MM-Clients are not multi-threaded. This is an intentional design feature incorporated for safety; MM-Clients only execute limited amounts of code before blocking for a continuation confirmation from the MM-Server, and in the future, a "kill server" on the local network. If at any point MM-Client connection with the MM-Server is lost, it ceases any commanded behaviors and reverts back to its initialization behavior, i.e., entering an "idle" loop, attempting to reconnect every ten seconds until successful.

3. Communication Protocol

The communication protocol between the MM-Server and the MM-Client is shown in the flow chart shown in figure two. The flow chart assumes that the MM-Server has a preexisting session established between one or more MM-Clients. When first initialized, the MM-Clients are in an idle state, as discussed above. When the trainer inputs a module command to be executed into the user interface, that command is written by the server to the inbox of the MM-Client. The MM-Client periodically (currently set to every five seconds) retrieves its inbox, then confirms the command with the "local kill" server. (The kill-switch feature is not yet implemented.) If it receives a "continue," the MM-Client updates its status on the MM-Server, and executes one iteration of the commanded behavior. At this point, it loops back to checking its inbox, and continues as above.

Behavior iterations are, and shall be, kept at an acceptably small duration, in order to allow the trainer or local kill server to cease behaviors in a reasonable amount of time, currently set to 10 seconds. As above, the MM-Client blocks while checking its remote inbox or confirming its command with the local kill server. If a halt is received in either situation, the MM-Client ceases behaviors, and reverts to an idle state.

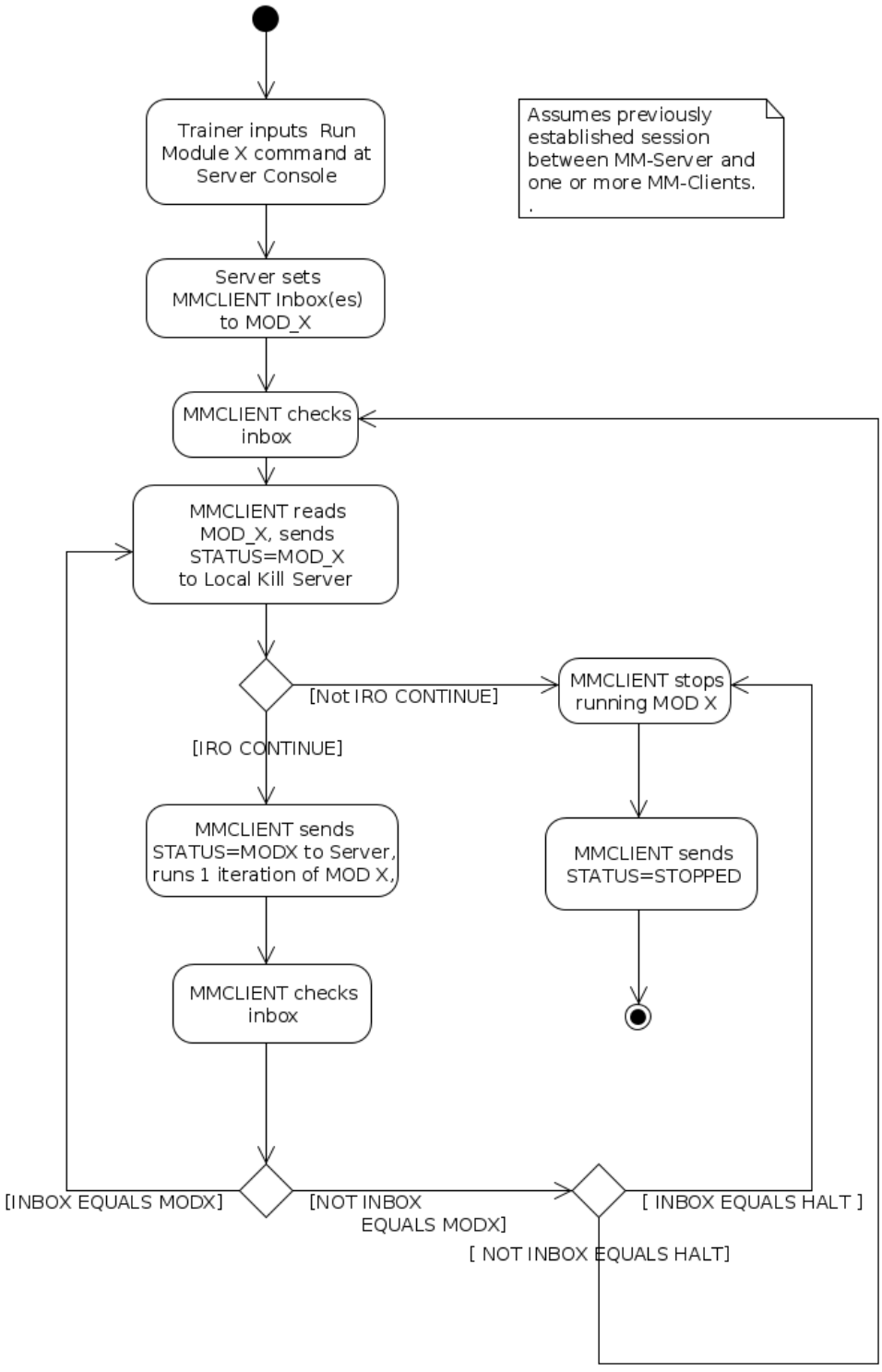


Figure 2. Communication protocol flow diagram.

The communications between the MM-Server and the MM-Client are passed in clear text, vice the host of other message passing facilities available in Java. The reason for this design decision was two-fold. First, the observable plain-text is much easier to troubleshoot. Second, the client-server session could utilize port 80, encapsulating the commands in Hypertext Markup Language, and in this way, be less likely to be flagged by any intrusion detection system that might be at a point between the MM-Server and MM-Client. This encapsulation feature is not yet implemented in the code.

4. Graphical User Interface for MM-Server

It was desired for this program to have a Graphical User Interface (GUI) as well. Once the MM-Server is adopted and is utilized to control hundreds to thousands of computers, then a GUI may be essential to ease the administrative tasks of monitoring the status of the MM-Clients, and controlling their behavior by issuing tasks to individual or groups of MM-Clients on the network.

The GUI was designed using the NetBeans Integrated Development Environment (IDE) 6.9.1. NetBeans provides an efficient and user-friendly design tool for developing rapid prototypes of graphical user interfaces. The tool also does a great deal of the coding of the layout; as the user establishes the look-and-feel of the interface by instantiating the frames, panes, and the locations of the fields, buttons, and labels, the coding is done in the background for the layout and format of all these items. This relieves the developer of much of the tedious tasks

associated with layout development and enables him to remain focused on the functionality to be provided.

The initial GUI design contains three different views: an icon-based view, a tree-based (or folder) view, and a tabular view. The tree-based view was implemented in this thesis, while the icon and tabular views are left for further study. The tree-based view is very similar to the file management tools in Windows, Macintosh, and Linux environments.

Each MM-Client is a node within a tree. By clicking on those nodes, the status of that MM-Client is displayed along with the ability to give new orders to the MM-Client. In time, the ability to select multiple MM-Clients and submit a batch order to the group will be implemented. Such a capability will enhance the controller’s ability to rapidly manage the training or evaluation scenarios.

C. BUILDING THE TEST PLATFORM

For our test, we built a small network of 20 nodes. In a real case of deployment, since our system is envisioned to be running as a distributed system, the MM-client software should be installed on many, if not all, devices in an organization connected to a MM-server. Therefore, it must be shown that the MM-server can handle the communication between multiple networked devices and that there would be a minimal delay from the time the command is given to a subset of MM-clients to the actual execution of that command. This delay should be dominated by the network-dependent characteristics of the messages, such as transmission,

propagation, and queuing delays, and not their processing by the MM-Server of MM-Client applications.

We designed a test platform based on virtualization for evaluating the MM-server and MM-clients. This test environment allows for greater flexibility in the types of operating systems utilized, minimal footprint taken up by equipment and cable runs, and for general expansion of the number of MM-clients run.

VMware's products were utilized in our thesis, in particular VMware View and VMware Workstation. These products will hereafter be referred to as a VMware Player. VMware allows many different Operating Systems to run as Virtual Machines on a single host platform. A Virtual Machine is essentially a complete, logical, computing machine. The user perceives the VM (Virtual Machine) as an entire computer solely running a particular Operating System and software. The VM is actually just another program being run by the host computer's Operating System (OS) with memory requirements. The file manager installed with the host OS allocates a large file on the hard drive which is accessed as a virtual disk from the VM. The VMware Player virtualization layer maps the actual physical resources of the host computer to the virtual machine's resources. Device driver support is inherited from the host OS. As such, activity inside the VM is handled by the host OS, device drivers, or directly by the hardware.

The VMware View or VMware Workstation program serves as a translator between the virtualized OS and the host computer. VMware translates desired commands into commands that must be scheduled and performed by the host's processor

and other resources. This translator is referred to as the hypervisor. A hypervisor is a piece of software that is closely tied to the host OS or to the host computer's hardware. Each VM is entirely encapsulated and must make all processor, resource, and device driver calls through this hypervisor. The hypervisor is in charge of coordinating all of these requests to the host OS or host computing machinery.

The host computer must have adequate hard drive space for a large file that will contain the VM's virtualized hard drive and sufficiently large physical memory (RAM) to be allocated to the VM's running process. The greater the number of virtualized hosts on a given platform the greater the demands for hard-drive space and RAM. A common and current computer can run the host OS and one or two VMs simultaneously. To do more requires a much more powerful computer.

Virtualization can be leveraged further—instead of using desktop computers, more powerful servers were utilized. The test platform was built utilizing two Dell PowerEdge 2950 Servers (eight 32-bit processors, 4 GB of main-memory (RAM), and 131 GB hard drive storage). These servers provide the capacity and performance required to run more than just a few VMs at once. Similar to the VMware View/Workstation program, a hypervisor is required to coordinate the use of the hardware's resources by the running VMs. VMware vSphere Hypervisor is a rebranding of what was previously known as VMware ESX and ESXi. The

vSphere Hypervisor runs on the “bare metal,” meaning that no host OS must be installed on the server in order to support the hypervisor.

Besides the two physical servers, a Dell Latitude E6510 laptop with an Intel i7 Core, 64-bit processor, and 8 GB of RAM was required. The laptop was our tool for creating VMs, converting them for use with the hypervisor, and transferring them to the physical servers. Once the VMs were transferred, the laptop was our means for controlling which VMs were active on the server, and for accessing inside each individual VM as if it were a separate computer awaiting our commands.

VMware View allowed us to create the VMs that would be installed onto the servers. Using the iso images of the Ubuntu 10.10, Ubuntu Server 10.10, and Windows XP Service Pack (SP) 3 Operating Systems, we created three individual VMs. Once the installation was complete, each VM was accessed and the additional software was installed: Java Runtime Environment, MM-Client, MM-Server, Wireshark, and hping.

VMware Converter allowed us to transport the VMs from the laptop to the servers. VMware Converter can take many different VM types and create a VM that is compatible with the hypervisor. These VM types include other VMware-based VM, Microsoft VMs, and other third party images, such as Norton Ghost images. The VMs and/or images must be loaded onto the servers hosting the hypervisor with VMware Converter. Failure to do so will result in VMs that do not work and that may possibly corrupt VMs previously loaded onto the server.

Once the VMs are loaded via the VMware Converter, the last required piece of software is used: VMware vSphere Client. This software is the management that that allows us to coordinate the actions of all the loaded VMs on the servers. Through the vSphere Client, all of the loaded VMs can be accessed. Similar to the VMware View program, these VMs can be started, stopped, suspended, or restarted. Once running, a console window can be accessed which allows the user to fully utilize the hosting system just as if it was on the controlling laptop. Furthermore, vSphere Client can provide statistics on each individual running VM or the entire physical server. Figure three shows the physical layout of the test platform along with the installed software.

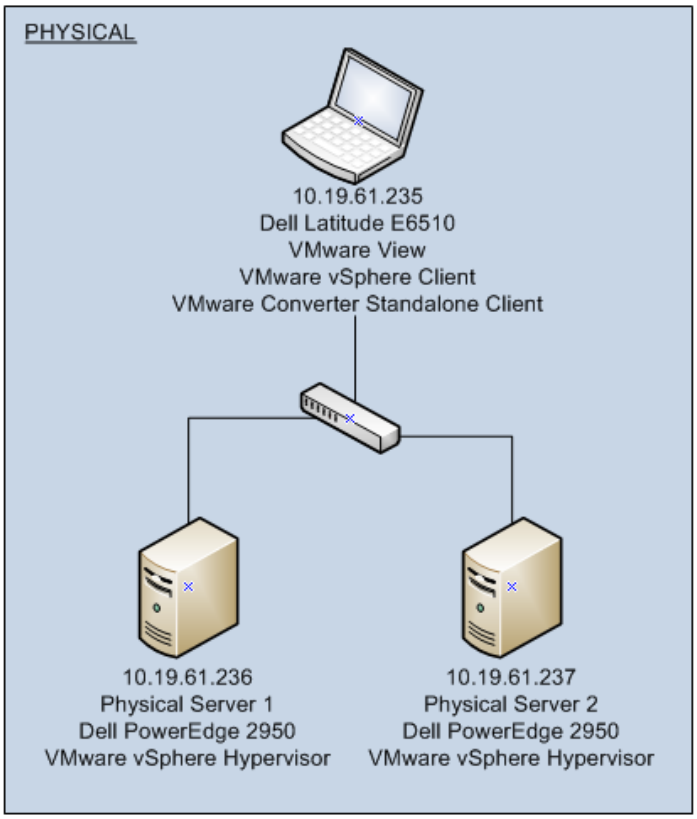


Figure 3. Physical test bed configuration.

D. EXPERIMENT DESIGN

The overarching goal of the experiment was to have a single running MM-Server with approximately 20 MM-Clients connected to it. Once all the machines were connected, we wished to show that the machines could be controlled in a timely fashion and that MM-Clients would generate an externally observable network behavior.

Another goal was to verify the MM-Server and MM-Client software could work on Windows and Linux environments. Most of the computers used by DoD commands are running Microsoft OS's: primarily Windows XP. For example, the Navy and Marine Corps Infrastructure and the shipboard IT-21 program also typically use Windows XP. Other OS's used within the DoD are Linux or Solaris based. It was mandatory that we verify that our code worked on the common platforms within the DoD and to prove the MM-Client's portability between the various OS's.

One obstacle identified in the setup of the experiment was the licensing limitations of the VMware vSphere Client. The VMware vSphere Client license is limited to ten activated VMs at any one time. Due to licensing restrictions, utilizing two servers, only twenty VMs can be running simultaneously. The physical servers can have more VMs installed, but only ten of those installed VMs can be activated at once. One VM was configured as the MM-Server. The other 19 ran the MM-Client software.

1. Operating Systems and Software Utilized

Each host, less one, was running the MM-Client software. One client was designated as the MM-Server; it

ran the MM-Server software. For each to run, the Java Runtime Environment (JRE) was installed on each machine. The JRE was downloaded from Java's website for the Windows XP SP3 VMs. The package openjdk-6-jre-headless was downloaded and installed on the Ubuntu and Ubuntu Server images. The operating systems utilized on the VMs were Microsoft Windows XP Service Pack (SP) 3, with all updates installed; Ubuntu 10.10; and Ubuntu Server 10.10. Section B.2 above has information about the software that was utilized for each of the modules. Again, Microsoft XP was selected, as it runs upon the preponderance of DoD workstations.

The MM-Server was run on an Ubuntu host VM. The MM-Server also served as the network monitor; towards this, MM-Client nodes were configured to direct network behaviors at the MM-Server. Utilizing the MM-Server's Module 0 (the initial and idle state for all of the MM-Clients), the MM-Client query the mailbox at the MM-Server for commands. In Module 1, the MM-Client sends a series of ICMP pings to the MM-Server. In Module 2, the MM-Client utilizes performs a SYN-scan of the MM-Server. All of the traffic was destined for the MM-Server whose computer would also be running Wireshark, a protocol analyzer. Finally, the MM-Server was also configured as a Dynamic Host Configuration Protocol (DHCP) server so that all of the VMs would not have to be assigned static IP addresses during test-bed startup.

It was desired for all traffic to be targeted to the MM-Server so that all communications and results of the running modules could be captured and analyzed. The experiment's goals were verification that the system worked,

verification of the timeliness with which the MM-Clients obeyed the commands, verification of correct behaviors of the MM-Clients running the modules.

Specifically, the test bed was set up as such:

- Command and Control Server
    - Ubuntu Operating System
    - MM-Server
    - DHCP Server
    - Wireshark
- Nineteen (19) Hosts
    - MM-Client receiving commands from the MM-Server
    - Assigned IP addresses from the DHCP server
    - Five (5) hosts running Ubuntu Desktop OS
    - Five (5) hosts running Win XP SP3 OS
    - Nine (9) hosts running Ubuntu Server OS

This is represented graphically in figure four.

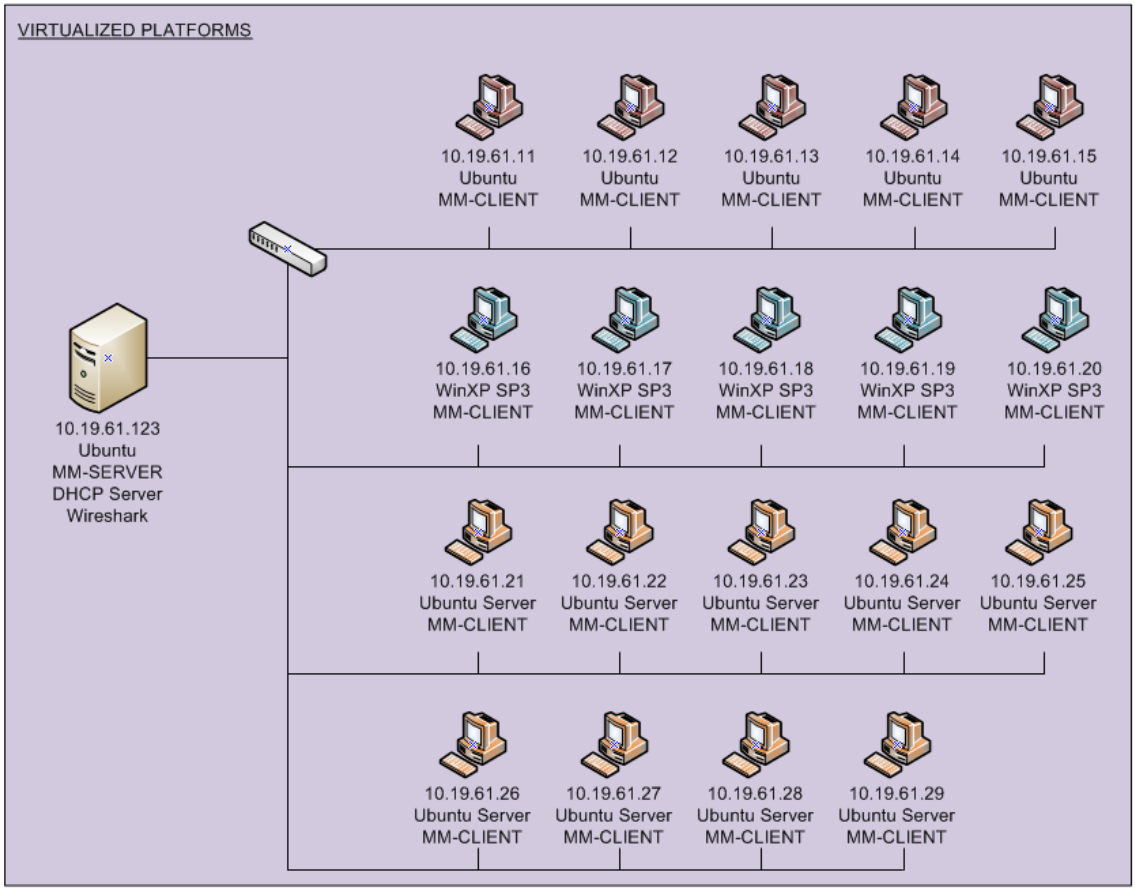


Figure 4. Virtual test bed configuration.

E. RUNNING THE EXPERIMENT

The VM that hosts the MM-Server, DHCP server, and Wireshark must be started first. Then, all of the other VMs may be started and the MM-Client software executed. While the MM-Clients connect to the MM-Server, status messages on the MM-Clients and MM-Server should be monitored to verify the connection made between the MM-Server and each MM-Client. Furthermore, Wireshark can be used to monitor the externally observable network behavior of MM-Clients querying their mailbox on the MM-Server for updated commands.

For purpose of our experiment, once all VMs and programs were started, we would verify that all programs respond to the changes of the requested running module by the MM-Server. Data would be analyzed using Wireshark to examine the change in network traffic directed at the MM-Server. Once all changes between module states zero to two were verified, each module would be run for up to five minutes to allow the system to reach a steady-state. Finally, the MM-Server would be stopped and Wireshark used to assess the changes in behavior of the MM-Clients as they changed from a running module to a failsafe state.

During all of the above, performance data would be captured about the server, to include CPU utilization, memory allocation, disk activity, network capacity used, and other statistics. The purpose of this data collection was to support an analysis of the strain under which the two servers are operating during this test.

The overarching purpose of this experiment would be to verify the system functions as designed. It would also be to verify that the MM-Server could handle multiple connections and that there would be timely changes in requested behavior by the MM-Clients. Finally, it would assess whether there was any strain upon the MM-Server or the physical servers themselves due to operation all of the virtual machines (this would indicate a scalability issue for a small deployment venue). As such, the experiment would serve to establish a benchmark for the performance of the Malware-Mimic System in a benign environment.

F. SUMMARY

This chapter discussed the system infrastructure consisting of the command and control MM-Server and the remote MM-Clients. The protocol's design was examined, specifically in relation to how the MM-Clients would receive the orders from the MM-Server. The protocol was designed with safety as the paramount feature. The MM-Clients must have guidance in order to start the modules. That guidance must persist for a new iteration of behavior to occur.

The test platform and the general design of the experiment were discussed. The test platform relies heavily upon virtualization. Virtualization allows for a varying number of systems to be activated, a variety of operating systems that can be utilized, and various network configurations, so that the MM-Server and MM-Client software can be fully vetted. It also forms a platform for further expansion in the formulation and testing of new modules, new operating systems, and more complex networks. The next chapter will provide the results of the experiment.

V. RESULTS

A. BACKGROUND

This section provides details about the implementation, as well as the results of the experiment delineated in Chapter IV. The results demonstrated the viability of this novel training and evaluation tool. The protocol functioned as it was designed, with feedback between the MM-Server and the MM-Clients. The safety features were adequate in restoring the MM-Clients to their failsafe state during interruptions in network connections with their respective MM-Sever. Observable network traffic was positively identified which can fulfill training and analysis objectives. Finally, it was verified that the test platform is a suitable testing environment prior to deployment on a live network.

B. SETUP

The two servers began the experiment in steady state with all VMs shutdown. On the laptop, we connected to each Physical Server utilizing vSphere. The Ubuntu VM that would run the MM-Server on Physical Server 2 was the first VM started. This was needed because that VM had a fixed IP address (10.19.61.123) and also hosted the DHCP server that would allocate IP addresses to all of the other VMs as they started up. Once the DHCP service was operating, all nineteen of the other VMs were started. Figure 5 shows which types of VMs were running along with their respective IP addresses on each physical server.

IP Address	Machine Name
10.19.61.236	Physical Server 1 - Running the Hypervisor
10.19.61.60	ubuntu_06_client - OS - Ubuntu
10.19.61.61	ubuntu_07_client - OS - Ubuntu
10.19.61.10	ubuntu_08_client - OS - Ubuntu
10.19.61.64	ubuntu_09_client - OS - Ubuntu
10.19.61.65	ubuntu_10_client - OS - Ubuntu
10.19.61.63	WINXP_06_client - OS - WinXP Pro SP3
10.19.61.66	WINXP_07_client - OS - WinXP Pro SP3
10.19.61.67	WINXP_08_client - OS - WinXP Pro SP3
10.19.61.68	WINXP_09_client - OS - WinXP Pro SP3
10.19.61.69	WINXP_10_client - OS - WinXP Pro SP3

IP Address	Machine Name
10.19.61.237	Physical Server 2 - Running the Hypervisor
10.19.61.11	ubuntuserver_01_client - OS - Ubuntu Server
10.19.61.12	ubuntuserver_02_client - OS - Ubuntu Server
10.19.61.13	ubuntuserver_03_client - OS - Ubuntu Server
10.19.61.14	ubuntuserver_04_client - OS - Ubuntu Server
10.19.61.15	ubuntuserver_05_client - OS - Ubuntu Server
10.19.61.16	ubuntuserver_06_client - OS - Ubuntu Server
10.19.61.17	ubuntuserver_07_client - OS - Ubuntu Server
10.19.61.18	ubuntuserver_08_client - OS - Ubuntu Server
10.19.61.29	ubuntuserver_09_client - OS - Ubuntu Server
10.19.61.123	MM-Server - OS - Ubuntu

Figure 5. Physical server IP addresses/type/names.

The specific IP addresses of the Physical Servers were not relevant for the experiment. The IP addresses facilitated connections via the laptop running the VMware vSphere Client software in order to control all of the VMs running on the servers. The controlling laptop was given an IP address of 10.19.61.235.

Physical Server 1 had five MM-Clients running on the Windows XP Professional Service Pack 3 (WINXP SP3) Operating System VMs, and five MM-Clients running on the Ubuntu 10.10

Operating System VMs. Physical Server 2 had nine MM-Clients, one per Ubuntu Server 10.10 VM, and the one MM-Server running on the Ubuntu 10.10 VM. All MM-Clients connected to the MM-Server at the IP address 10.19.61.123. The IP addresses were required so that the Wireshark packet capture could be analyzed in order to ensure all of the MM-Clients were executing the correct module and to get a measurement on how quickly each responded to the change in commands.

C. TIMELINE

Label	Time	Action
A	1:20 PM	Physical Laptop (10.19.61.235) connected to both running Physical Servers 1 and 2
B	1:21 PM	Server 2 (10.19.61.237): toggled on VM 10.19.61.123 (the Ubuntu VM that has MM-Server)
C	1:22 PM	Server 2 (.237) > Ubuntu VM up (.123), Wireshark and DHCP server up
D	1:22 PM	Server 2 (.237): toggled on the nine other Ubuntu Server OS VMs
E	1:23 PM	Server 1 (.236): toggled on the five WinXP and five Ubuntu VMs
F	1:23 PM	Server 2 (.237) > Ubuntu OS VM (.123) started MM-Server listening for incoming connections on port 30000
G	1:23 - 1:28 PM	Server 2 (.237) > all Ubuntu Server OS VMs up, all MM-Clients connected to MM-Server
H	1:28 - 1:35 PM	Server 1 (.236) > all WinXP and Ubuntu VMs up, all MM-Clients connected to MM-Server
I	1:35 PM	MM-Server (.123) shows all nineteen MM-Clients connected
J	1:35 PM	MM-Server (.123) issues run MOD_1:ALL command
K	1:40 PM	MM-Server (.123) issues run MOD_2:ALL command
L	1:45 PM	MM-Server (.123) issues run MOD_0:ALL command
M	1:50 PM	MM-Server (.123) issues run MOD_2:ALL command
N	1:53 PM	Turn off MM-Server, verify all Clients return to MOD_0 behavior
O	1:54 - 1:59 PM	Server 1 (.236): Shutdown all VMs
P	1:59 - 2:02 PM	Server 2 (.236): Shutdown all VMs

Figure 6. Experiment Timeline of Events.

The timeline (Figure 6) shows the order and times of specific events during the entire experiment. This helped us correlate the information in all of the packets displayed in Wireshark with the events that occurred. Furthermore, this timeline is meant to be used in conjunction with Figures 8 and 9 (showing CPU utilization per physical server). The alphabetical labels on Figures 8 and 9 correspond to the same labels in the left hand column in the timeline shown in Figure 6.

D. DISCUSSION OF RESULTS

Overall, the entire experiment verified system performance per the architecture set forth in Chapter II. All VMs functioned as configured, and all MM-Clients connected to the MM-Server performed the desired actions and responded to the changes in commands in less than ten seconds. The MM-Server had no dropped packets on the Network Interface Card and Wireshark showed all of the traffic between the MM-Clients and the MM-Server.

1. Results for MM-Server and MM-Clients

The MM-Server performed according to specification. All MM-Clients connected to the MM-Server as designed. The Ubuntu VM hosting the MM-Server operated with no degradation in performance under the load of the nineteen TCP sessions of the MM-Clients. The Linux “top” command showed that the Java process of the MM-Server utilized approximately 0.3% of the CPU time. It also showed that the percent of memory utilized by the same process started at 2.5% when no MM-Clients were connected and only grew to 2.9% when all nineteen MM-Clients were connected.

An example of the time it takes to transition between states for the MM-Client is given below. Since the MM-Server does not actively send a command to a MM-Client, the responsiveness between a typed command at the MM-Server and the MM-Client receiving that command, updating the MM-Client’s status and then executing that command is somewhat slower than it could be. However, as seen in Figure 7, it takes approximately 5-6 seconds for a MM-Client to cease the current running module, access and process the new order

from its mailbox in the MM-Server, update its status with the MM-Server and begin exhibiting the correct behavior of the newly ordered module. This delay can be attributed to many different processes: physical, programmable, and virtual. The physical realm deals with the actual signal propagating through the physical wires and switch. Within the programs, the command is placed within the MM-Client's inbox on the MM-Server and there is a delay depending on when the MM-Client "checks back in" with the MM-Server following a single iteration of the current ordered module. Finally, since there are two physical servers running twenty VMs, there are additional delays due to the non-deterministic scheduling of the VMs, as well as the overhead of the hypervisor.

Time	From	To	Packet ID	Command/Response	Comment
13:35:51.218740	.67	.123	13649	GETINBOX	MM-Client querying INBOX
13:35:53.256175	.123	.67	13653	INITIALIZED	MM-Server responds: your INBOX command says INITIALIZED (continue running MOD_0)
13:35:56.218650	.67	.123	13803	GETINBOX	MM-Client querying INBOX
13:35:56.256142	.123	.67	13807	MOD_1	MM-Server responds: run MOD_1 (ping me)
13:36:01.218671	.67	.123	13951	STATUS=MOD_1	MM-Client: received command to run MOD_1
13:36:01.340926	.67	.123	13957	PING .123	MM-Client pings MM-Server - correct behavior for MOD_1
…	…	…	…	…	MM-Client running MOD_1
…	…	…	…	…	Last 5 Pings of MOD_1, now check inbox
13:40:09.865639	.67	.123	25560	GETINBOX	MM-Client querying INBOX
13:40:09.866071	.123	.67	25564	MOD_2	MM-Server changes command to run MOD_2 (SYN Scan)
13:40:14:856811	.67	.123	25744	STATUS=MOD_2	MM-Client: received command to run MOD_2
13:40:15.143224	.67	.123	25755	SYN Scan of .123	MM-Client begins SYN Scan of MM-Server
…	…	…	…	…	MM-Client running MOD_2
…	…	…	…	…	Last SYN scans of MOD_2, now check inbox
13:45:15.440065	.67	.123	58310	GETINBOX	MM-Client querying INBOX
13:45:15.440178	.123	.67	58312	MOD_0	MM-Server responds: return to idle, run MOD_0
13:45:20.402246	.67	.123	58536	STATUS=MOD_0	MM-Client: received command to run MOD_0

Figure 7. Packet Capture between MM-Client and MM-Server.

The MM-Clients were designed for safety and the ability to be controlled remotely. Figure 7 is a sample of the latter, utilizing a Wireshark packet capture between the MM-Client hosted on the WINXP_08_Client (10.19.61.67) and MM-

Server (10.19.61.123). To test the former, the experiment ended with an abrupt termination of the MM-Server with all nineteen MM-Clients having active TCP sessions. The ensuing network traffic from the MM-Clients to the host which had been previously running MM-Server at 10.19.61.123 was captured by Wireshark. Within seven seconds, all of the MM-Clients that were running Module 2 entered their failsafe behavior. All MM-Clients performed as expected, which suggests that the built-in safety mechanism performed as planned. That is, if the MM-Server is no longer present to give orders, the MM-Clients will terminate all previous behaviors, revert to a benign, failsafe mode, and attempt to reestablish a connection with the MM-Server.

2. Results for the Physical Servers

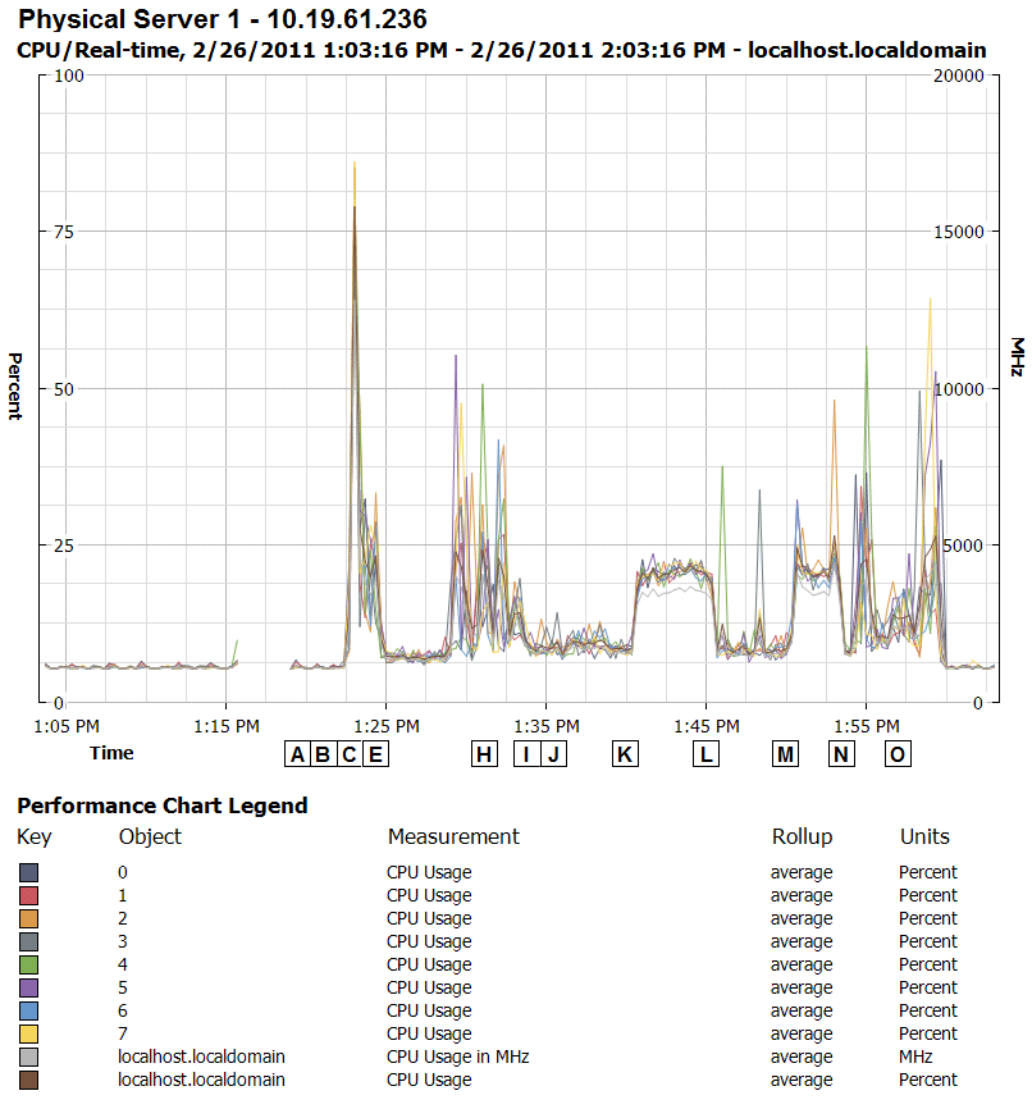


Figure 8. CPU Utilization of Physical Server #1.

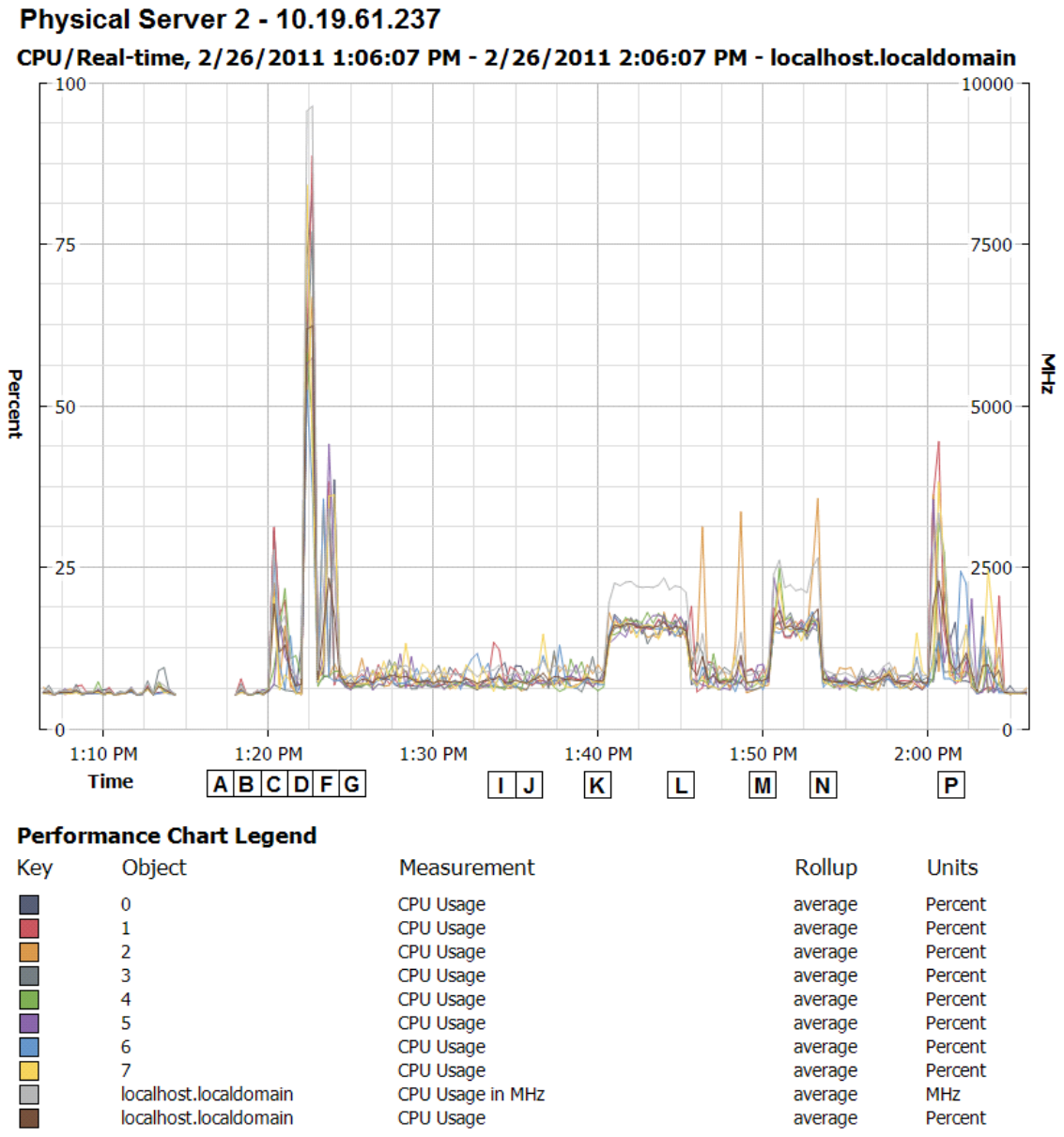
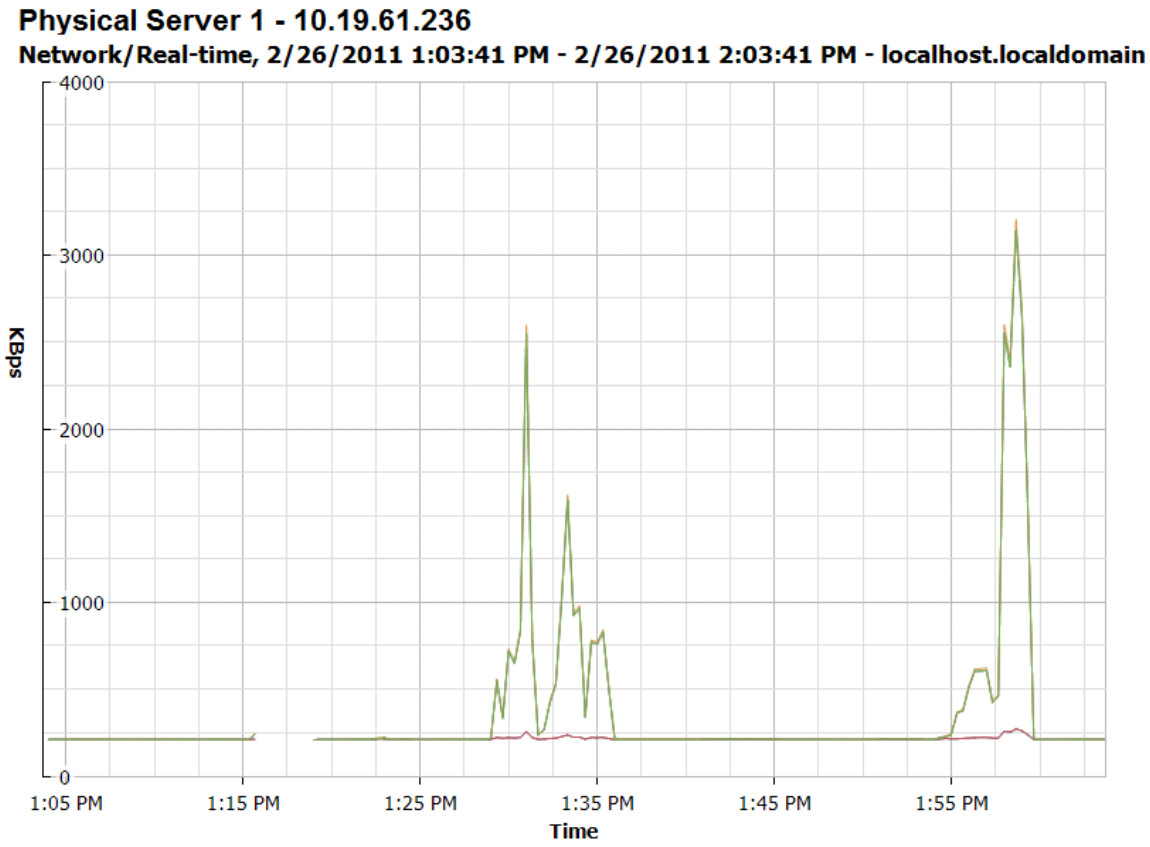


Figure 9. CPU Utilization of Physical Server #2.

The performance of physical servers one and two (IP addresses (10.19.61.236 and 10.19.61.237, respectively) running the hypervisor and all of the VMs matched expectations. According to the CPU utilization graphs (Figures 8 and 9), the large spikes in CPU utilization were

the actual starting and stopping of the VMs (points D and E). The other large spikes occurred at points G and H, when all of the MM-Client software and Java Runtime Environment was activated.

After the MM-Clients were started and connected to the MM-Server, CPU utilization of the actual physical servers was negligible. The initialization and idle state (Module 0) had the MM-Clients communicate once every ten seconds to the MM-Server in order to check for messages in their respective queue (Module 0 began at Labels I and L in Figures 8 and 9). This activity had a negligible effect on the CPU, even though the CPU is “serving” both the MM-Server and the MM-Client entities. Module 1 is not CPU-intensive, calling only a series of five pings back to the MM-Server per MM-Client instantiation for the module cycle of ten seconds (Module 1 began at Label J in Figures 8 and 9). Module 2 activated another process, hping, in order to perform a SYN scan of the MM-Server. This shows an increase of about 15-20% CPU utilization on both physical servers (Module 2 began at Label K in Figures 8 and 9). The physical servers handled the swapping between the ten VMs and the network traffic between the MM-Server and MM-Clients as expected.



Performance Chart Legend

Key	Object	Measurement	Rollup	Units
	localhost.localdomain	Network Data Receive Rate	average	KBps
	vmnic0	Network Data Receive Rate	average	KBps
	localhost.localdomain	Network Usage	average	KBps
	localhost.localdomain	Network Data Transmit Rate	average	KBps
	vmnic0	Network Data Transmit Rate	average	KBps

Figure 10. Network Utilization of Physical Server #1.

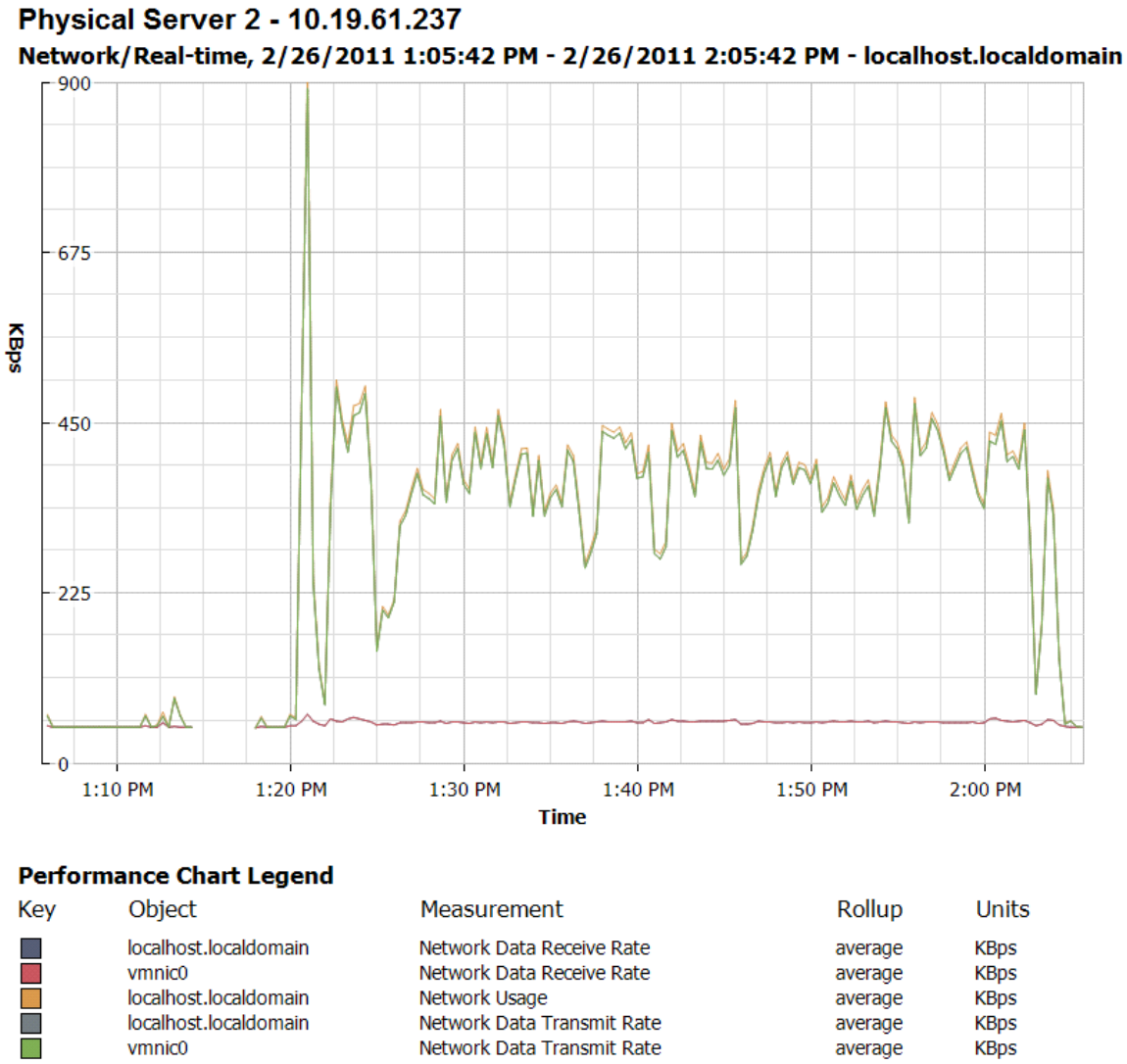


Figure 11. Network utilization of physical server #2.

Hard disk activity of the physical servers was negligible. Main memory (RAM) usage by each of the physical servers was as expected when running all of the VMs: approximately half of the onboard memory was utilized. Each physical server had 4 GB of main memory. Upon startup of all the VMs, memory peaked to almost full utilization. Once all the VMs were fully booted up, logged into, and the MM-Server and all MM-Clients activated, memory usage was

approximately 25-50% in steady state. It is to be noted that for future work, if more VMs are to be run concurrently, the onboard memory should be increased to 8 or 16 GB.

Network activity of the physical servers due to the Malware Mimic system is harder to isolate and assess. As seen in Figures 10 and 11, overall network traffic was well within the Gigabyte Ethernet capability of the server Network Interface Cards and the switch. However, there are some large spikes in network traffic that must be explained. In Figure 10, the network traffic for Physical Server 1 (.236), there were large spikes of approximately 2-3 megabytes per second (MBps) at the setup and shutdown of the experiment and it was mostly steady around 200 kilobytes per second (KBps) during the actual running of the different MM-Client modules. The large spikes of 2-3 Mbps were due to the external connection of the laptop that contained the vSphere Client software. Through vSphere, we utilized the remote console window to access every VM. Once we were logged in to each VM and the MM-Client software was started, the now unneeded VM remote consoles were closed. At the end of the experiment, the VMs were remotely logged into again, in order to stop the MM-Client software and shutdown the VMs. The vSphere Client allowed a remote console window, giving full access to each VM as if sitting at a normal desktop computer. All of these live video feeds of the running VM to our remote console were sent over the network connection from the Physical Servers to the laptop. This explains the large spikes at the beginning and end of the experiment as seen in Figure 10.

The network activity of Physical Server #2 (.237), shown in Figure 11 was similar to that of Physical Server #1, with the large 900-KBps spike at the startup of all the VMs. This is less because the Physical Server #2 has nine Ubuntu Server OS VMs running. The Ubuntu Server OS is accessed from a command prompt. This interface was text-based, unlike the graphical interfaces of the Ubuntu Desktop OS and WinXP OS. Therefore, the amount of information sent over the network to our remote console was significantly less than the graphical environments of Ubuntu and Windows XP. However, during the period when the different MM-Client modules were being accessed, Physical Server #2 has about twice the network activity. This can partly be explained by the fact that the Ubuntu OS VM (.123), with the MM-Server software on Physical Server #2, was the only remote console utilized to control all of the MM-Clients. Therefore, the live feed from that VM was sent over the network to the external laptop in order to control the flow of the experiment.

To isolate the network traffic resulting solely from the VMs, Wireshark statistics from the Ubuntu VM running the MM-Server was used. Wireshark provided an input/output graph of the amount of packets (or bytes) per unit time. The output was configured for bytes per second. During the test run, with all MM-Clients running Module 0 (idle state), traffic to and from the MM-Server was 0.5-3 KBps. When all MM-Clients were running Module 1 (ping), traffic was 1.5-8 KBps. When all MM-Clients were running Module 2 (SYN scan), traffic was 4.5-8 KBps. Comparing these numbers to the graphs in Figures 10 and 11, we discovered that there is a significant amount of network traffic overhead for the

virtualization of network traffic as well as the live video feed for the remote console capability. In comparison, if the MM-Server and MM-Clients were utilized on a live, operational network, the resulting network activity of 0.5-8 KBps would be relatively insignificant compared to the 10, 100 or 1000 MBps capacity of today's networks.

E. SUMMARY

The experiment demonstrated that our system performed as designed. All of the test goals were accomplished and there was an observable validation for each portion of the experiment. This included the most important of the goals: demonstrating the ability to control the MM-Clients in a timely manner. The MM-Clients were all responsive in changing to the ordered module, and when communication to the MM-Server was severed, all MM-Clients ceased their current activity and entered their failsafe mode.

The results also show that the client-server relationship worked correctly, and can likely scale to a greater number of MM-Clients operating on differing network configurations. Also, with the exception of possibly needing additional onboard memory for the Physical Servers, there is plenty of capacity with respect to CPU cycles, hard drive space, and network utilization for each of the physical test bed servers to accommodate more simultaneous VMs, as well as more complex network configurations.

Next, in Chapter VI, we discuss our conclusions. We also discuss our thoughts on future work in this area of study, to include code improvement, expansion, and security implications.

VI. CONCLUSIONS AND FUTURE WORK

A. CONCLUSIONS

In this thesis, we proposed a solution to DoD overreliance on network analysis red teams for training and evaluation of network administrators by designing a novel network training tool. This tool allows the integration of network evaluation into the highly complex training events typical of U.S. military training exercises. The system we constructed had the following characteristics:

- It was safe enough for production or operational environments. Emulated behaviors would cease on command and “roll-back” to a pre-exercise state. Losses of network connection were treated as instructions to cease behaviors. This would allow training to take place on the same network on which the trainees perform their mission.
- Only malware behaviors were constructed, not actual malware itself. Though we demonstrated the properties of a notional worm on the network, there was no actual malware involved.
- The system constructed was distributed across the network, allowing for the trainer to be located anywhere on the network, local or remote.

We then set out to construct a prototype for such a system, which we discussed in detail in Chapter IV. Following our treatment of the constructed system, we discussed the test bed that we created to test our system

concept vis-à-vis the goal we had set for ourselves, and proceeded to discuss the specific results acquired after establishing the test-bed and conducting a set of tests.

We discovered that it is certainly possible to construct a system with the attributes discussed above. We believe that this has the potential to revolutionize training for not only network administrators, but for the decision makers that are affected by malicious actions against such networks. We also noted that the system performs as expected with regards to safety, namely, that it did not perform uncommanded behavior at any point during testing. The system ceased all emulated behaviors within a suitable small time upon receipt of the trainer injected "cease-action" command—without exception. This particular system quality is essential for its forecasted use on operational networks, and in this capacity, the MM-System is ready for a validation in an operational or production environment.

We also discovered we essentially built a botnet, as discussed in Chapter II, complete with a command and control architecture and slave-node functionality without the dangerous behavior of actual propagation across the network. This, we believe, could form the basis of an existence proof for the size to which our Malware Mimic System architecture can scale. Using Conficker as an example (also discussed in Chapter II), it is possible that this tool could scale to thousands of hosts, with some modification to the code, allowing the training and evaluation of the administrators of networks on the order of Tier One Internet Service Providers.

B. FUTURE WORK

1. Code Improvement and Extension

As with any software early in its lifecycle, the code needs refinement. For example, we found that the keying system for our data structure (mapping between keys and actual nodes) was unwieldy. It is essential that this key uniquely correspond to a MM-Client node, which we accomplished by using a combination of the given node's host name and a user assigned name given at invocation. However, this does not scale well, as it requires a unique naming system to be created and tracked by those parties responsible for instantiating the nodes. Instead, we would suggest using a naming scheme that would allow for unique names to be generated and maintained by the hosts themselves, without involvement by any human user. Furthermore, the Data Structure will, at some point, need to be replaced by a robust, industrial grade database that can maintain records on the order of thousands, vice the data structure we utilized, discussed in Chapter III.

We described a local "kill server" and its role in the communication protocol of the MM-Mimic system in Chapter III, but we provided no implementation. We foresee a modification to the MM-Client code that allows for local pre-emption or blocking of remote taskings using UDP-based requests to local "kill server" located on the trainee network. Construction of this "kill server" could largely be modeled on the MM-Server architecture discussed in Chapter III; again, using datagram vice stream socket connections.

There are several improvements that could affect the scalability of the software. As it stands, there is no organic capability implemented to remotely “push” MM-Client code to machines on the trainee network. Additionally, there is no capability to distribute updates over the network. The implication of this is that the MM-Client nodes must have all desired behaviors preprogrammed into the MM-Client software on the host machine. A more agile solution would be to have modules of behaviors sent to MM-Client nodes via software push, increasing the flexibility, adaptability, and, possibly, security of the MM-Mimic system. Such a scheme would require authentication and integrity verification to ensure only authorized behaviors are distributed.

2. More Advanced Modules

The training value in our first iteration of the MM-System is limited. That said, there is a rich framework laid out upon which more complex modules, with corresponding training scenarios, could be developed. We foresee modules that would allow the MM-Client nodes to mimic virus behavior, as outlined in Chapter II, including, but not limited to host machines showing virus “signatures” that would be visible on installed anti-virus systems. Such signatures would need to be “hidden,” likely through encryption, until the behavior is commanded. MM-Client nodes could show “pop-up” messages that would instruct users to contact their system administrators. MM-Clients could increase their system resource consumption, increasing the discomfort level of human users utilizing the system. More advanced and realistic worm behaviors could be programmed;

simulation of worm behaviors propagating across a network, or delivering a “payload” would be an example of this.

We have limited ourselves to discussing the behaviors of malware—worms, botnets and the like. However, human-centric behavior continues to be a critical aspect of system hardening. Emulating such behavior to train operators to recognize it when it occurs could be beneficial. Determining whether or not there exists discernable differences between the observable behaviors of a human adversary, a “hacker” in popular parlance, and programmatic behaviors of the MM-System would be a first step to implementing “human” behaviors. We believe that the emulated threat behaviors of the MM-System could be expanded to include those of “hackers” as well, perhaps through well-scripted “mock” user-sessions.

3. Increase Scale of Test Bed

Code development is one area for further advancement; but the path forward for the project in the whole will rely on the system being tested on human users on a scale representative of the training networks to which the system is destined. Towards this, expansion of the test bed will be required to an appropriate number of clients well beyond the twenty used for initial test bed. Testing of the system should also be conducted on networks more complex than the single subnet system we utilized, again, to validate the system for networks more representative of its anticipated use. Additionally, as discussed in Chapter V, we relied on a protocol analyzer to demonstrate our externally-observable

network behaviors. We must additionally test our system against common intrusion detection systems used in the field today, e.g., Snort.

4. Security Implications

We made no security assumptions in our architecture, nor did we treat security implications in our experimentation. Before the MM-System is ready for field use, security analysis must be performed. The architecture should be suitable for this environment, however, as the system architecture was conceived with security in mind, with an eye on eventual deployment on DoD networks. Java is common on DoD networks. Host-based network software is common on DoD networks. No mechanism yet exists to prevent unauthorized third parties from remotely commanding MM-node behavior, but again using existing botnets such as Conficker as an example, this too should be possible. But the fundamental approach to the system is its greatest asset: only malware *behaviors* are employed on the trainee network, not actual malware. Therefore, no behavior can happen on the network that is not explicitly coded into the MM-Clients. In this way, the MM-System behaviors can be tailored according to the risk tolerance of the trainee networks.

APPENDIX A. MM-SERVER: CANDCSERVER.JAVA

```
/*****************************************************************/
/*                                                               */
/*      Program:  Malware Mimic Server                           */
/*                                                               */
/*      Top level for the MM-Server.  Interfaces with the user   */
/*      via the UI. Handles incoming TCP connections on all      */
/*      interfaces on TCP.port == 30000 with remote or local     */
/*      MM-Clients.  Maintains and closes TCP sessions with      */
/*      MM-Clients.  Translates user instructions to MM-Clients  */
/*      and passes the commands to MM-Clients.  Allows input     */
/*      from MM-Clients to UI.  Maintains state on MM-Clients.   */
/*      FILE:       ClientProgram.java                           */
/*                                                               */
/*      USAGE: ./MM-Server <with no paramters>                   */
/*                                                               */
/*                                                               */
/*      AUTHORS: W. Taff and P. Salevski                         */
/*                                                               */
/*      DATE: 22 January 2011                                    */
/*                                                               */
/*****************************************************************/


package commandserver;

import java.io.IOException;
import java.net.*;

/**
 * The server - top level for program, and listener for connections.
 * Initializes the database.  Starts the UI.
 * Sits and listens for connections, spins off CC-Communicators
 * to handle them and passes off Socket to same, then reset to
 * listen.
 *
 * @author W. Taff and P. Salevski
 *
 */
public class CandCserver {

        /**
         * @param args
         */
        public static void main(String[] args) {


                ////////////////////////////////////////
                //INITIALIZATION
                ////////////////////////////////////////

                ClientDatabase dataBase = new ClientDatabase();
```

```
                Integer listenPort = 30000;

                Socket clntSock = null;


                //start the UI
                Thread GUIthread = new Thread(
                                new CandCserverMenuUI(dataBase));
                GUIthread.start();



                try {
                        ServerSocket server = new ServerSocket
                               (listenPort);

                        System.out.println ("Server Listening on port "



                        while (true){

                                System.out.println ("Waiting");

                                clntSock = server.accept();

                                System.out.println ("Connection Accepted
                                   from " + clntSock.getInetAddress() );

                                Thread thread = new Thread(new
                                ClientCommunicator(clntSock, dataBase));

                                thread.start();


                        }//end while

                }
                catch (IOException ioe) {
                        System.err.println (ioe);
                }


        }

}
```

APPENDIX B. MM-SERVER: CANDCSERVERMENUUI.JAVA

```
package commandserver;
//Filename: CandCserverMenuUI.java
//21 December, 2010

import java.util.Scanner;

/**
 * Rudimentary command line, console based ui
 * Used for troubleshooting and functionality verification; will
 * likely be replaced with graphical version.
 *
 * @author W. Taff and P. Salevski
 *
 */
public class CandCserverMenuUI implements Runnable {


        /** need access to db to invoke methods */
        private ClientDatabase db;



        public CandCserverMenuUI(ClientDatabase dbInput){

                this.db = dbInput;}




        /* (non-Javadoc)
         * @see java.lang.Runnable#run()
         */
        public void run() {

                uiConsole();


        }//end run




        private void uiConsole() {

        //OF FORM: commands, module numbers (if any), and targets
                // e.g. MOD_0:ALL  or maybe PRINT:ALL
                // if no target, assume ALL

                Scanner adminInputScanner = new Scanner(System.in);
```

```
String inputString = "";

int cmdDelimValue;

String command = null;

String target = null;

int moduleNumber = 999;

while (inputString.compareTo("QUIT")!=0){

        inputString = adminInputScanner.next();

        inputString = inputString.toUpperCase();

        cmdDelimValue = inputString.length();


        try {
                if (inputString.contains(":")){

                      cmdDelimValue =
                      inputString.indexOf(":");

                command = inputString.substring(0,
                                cmdDelimValue);

                target =
                inputString.substring(cmdDelimValue
                        + 1);   }

                else {

                        command = inputString;

                        target = "ALL";

                }


                if (inputString.contains("_")){

                        int modDelimValue =
                        inputString.indexOf("_") + 1;


                        moduleNumber =
                        Integer.parseInt(inputString.
                        substring(modDelimValue,
                        cmdDelimValue) );

                        command = command.substring(0,
                        modDelimValue -1 );
```

```
                }

            } catch (Exception e) {
                e.printStackTrace();

                System.out.println("ERROR ON PARSE OF
                INPUT");

            }

            System.out.println("Command is:"
                        + command );

            System.out.println("Target is:"
                        + target );

            System.out.println("Module Number is:"
                        + moduleNumber );

            //THE COMMANDS

            if (command.compareTo("PRINT") == 0){
                print(target);
            }

            else if (command.compareTo("HALT") == 0){
                halt(target);
            }
            else if (command.compareTo("MOD") == 0){
                mod(moduleNumber, target);
            }
            else {
//                  db.getRecord(command).getCC().
//
```

```
sendMessage2Client(value);
                }//end else

        }//end while
        System.out.println("Got quit command");
        System.exit(0);
}




private void mod(int moduleNumber, String target) {
        System.out.println("Running MOD_" + moduleNumber);
        db.run_module(moduleNumber);
}



private void halt(String target) {
        if (target.compareTo("ALL")==0){
        System.out.println("Halting All!");
        db.halt_module();
        }
}




/**
 * Print records in the database.
 * @param target
 */
private void print(String target) {
```

```
                if (target.compareTo("ALL")==0){
                        String printBuffer = db.getAllrecordsFromDB();
                        System.out.println("Host, Exercise, Inbox,
Status");
                        System.out.println(printBuffer);
                }//endif

        }//END print()
}//end class
```

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APPENDIX C. MM-SERVER: CLIENTCOMMUNICATOR.JAVA

```
// Filename: ClientCommunicator.java
// 21 December, 2010

package commandserver;

import java.net.*;
import java.io.IOException;
import java.io.PrintStream;

/**
 * A handler that maintains the session between server and client.
 * Runs as a thread that is started by server.  On run, spins off
 * a threaded Client Listener to accept input, and calls MM-node
 * for Name and Status.
 *
 * @author W. Taff and P. Salevski
 */
public class ClientCommunicator implements Runnable{


        /** Socket passed to CC by the SocketServer  */
        private Socket ccSocket;

        /** The output stream use to push our messages onto the wire  */
        private PrintStream outPrintStream;


        /** the location of the db, so we can call it's methods */
        private ClientDatabase db;

        /** the keyname of the host that the CC relates to */
        private String keyname;


        // CONSTRUCTOR
        public ClientCommunicator(Socket passedSocket,
                        ClientDatabase db) {

                this.ccSocket = passedSocket;

                this.db = db;

                //make the output stream.  input stream made in run()
                try {

                        this.outPrintStream = new PrintStream(
                                        ccSocket.getOutputStream() );

                } catch (IOException e) {

                        e.printStackTrace();
```

```
        }

}//end constructor ClientCommunicator()




        /* (non-Javadoc)
         * @see java.lang.Runnable#run()
         */
        //@Override
        public void run() {

                ccListenerStarter() ;

                outPrintStream.println("#GETNAME");

        }//end run()




        /**
         * Starts the ccListener.
         * Use the ccListener for input from the MM-node. */
        private void ccListenerStarter(){

                try {

                        //spin off new ccListener

                        Thread listenerThread = new Thread(
                        new ClientCommunicatorListener(
                        ccSocket.getInputStream(), db, this));

                        listenerThread.start();



                } catch (IOException e) {

                        e.printStackTrace();

                }


        }//end ccListenerStarter()
```

```
/**
 * Externally callable session terminator-closes socket.
 * Also updates the status of the MM-Client in the db.
 */
public void terminateSession(){

        sendMessage2Client("Session Terminated");


        db.getRecord(keyname).setClientStatus("TERMINATED
        ");

        try {

                ccSocket.close();

        } catch (Exception e) {

                e.printStackTrace();
                db.getRecord(keyname).setClientStatus("LO
                ST");

        }


}//end terminateSession()




/**
 * Pushes any input string down to MM-Client
 * @param msg
 */
public void sendMessage2Client(String msg){

        outPrintStream.println(msg);

}



/**
 * @return the keyname
 */
public String getKeyname() {
        return keyname;
}
```

```
                /**
                 * @param keyname the keyname to set
                 */
                public void setKeyname(String keyname) {
                        this.keyname = keyname;
                }


}//end class
```

APPENDIX D. MM-SERVER: CLIENTCOMMUNICATORLISTENER

```
package commandserver;
//Filename: ClientCommunicatorListener.java
//21 December, 2010


import java.io.*;

/**
 * @author W. Taff and P. Salevski
 * Handles input from MM-node.
 * Parses MM-node messages and makes appropriate system calls.
 *
 */
public class ClientCommunicatorListener implements Runnable{

   ////////////////////////////////////////
   //DATA MEMBERS
   ////////////////////////////////////////


   /** passed - will bolt on top a BufferedReader */
   private InputStream inStream;

   /** use for reading incoming messages from MM-Client */
   private BufferedReader inBufferedReader;

   /** gives ability to call ClientDatabase fns  */
   private ClientDatabase db;

   /** gives ability to call back to the calling CC */
   private ClientCommunicator parentCC;




   ////////////////////////////////////////
   //METHODS
   ////////////////////////////////////////


   //CONSTRUCTOR
   public ClientCommunicatorListener(InputStream inputStream,
         ClientDatabase db, ClientCommunicator callingCC) {

      this.db = db ;

      this.inStream = inputStream;

      this.inBufferedReader =
         new BufferedReader(new InputStreamReader(inStream));
```

```
   this.parentCC = callingCC;

}


public void run() {

   //Need try/catch to make severed sessions graceful
   try {

      listenLoop();

   } catch (NullPointerException e) {

      e.printStackTrace();

   }

   catch (Exception e) {

      e.printStackTrace();

   }

   finally {

      System.out.println("Connection Lost to " +
            parentCC.getKeyname());

      parentCC.terminateSession();
       db.getRecord(parentCC.getKeyname()).setClientStatus("LOST");

   }


}//end run()







/**
 * Main loop of CCListener.
 * Blocks on readlines from MM-Client.  Calls appropriate db
 * methods based on input passed up from MM-Client.
 * @throws Exception
 *
 */
private void listenLoop() throws Exception {

   Boolean keepGoing = true;

   String textReceived = "";
```

```
   while ( keepGoing ) {

      textReceived = inBufferedReader.readLine();

      if ( textReceived.compareTo("QUIT")==0 ){

         parentCC.terminateSession();

         keepGoing = false;

      }

      else if ( textReceived.contains("GETINBOX")){

         parentCC.sendMessage2Client(db.getRecord(
               parentCC.getKeyname()).getClientInbox() );

      }


      else if ( textReceived.contains("=") ){

         setVariableValue(textReceived);


      }//end if

      //RESET THE TEXT OR WE SPIN
      textReceived = "";


   } // end while

}







/**
 * Set a db key/value pair based on input from MM-client
 *
 * @param textReceived
 */
private void setVariableValue(String textReceived) {

   int delimValue = textReceived.indexOf("=");

   String key = textReceived.substring(0, delimValue);

   String value = textReceived.substring(delimValue + 1);
```

```
      if (key.compareTo("NAME")==0) {

         parentCC.setKeyname(value);

         db.createRecord(value, parentCC);

      }

      else if (key.compareTo("STATUS")==0) {

         //with key, set the status
         db.getRecord(parentCC.getKeyname()).setClientStatus(value);

      }


      else if (key.compareTo("EXERCISE")==0){

         db.getRecord(parentCC.getKeyname()).setExercise(value);

      }

   }

}
```

APPENDIX E. MM-SERVER: CLIENTDATABASE.JAVA

```
package commandserver;
// Filename: ClientDatabase.java
// 21 December, 2010


import java.util.TreeMap;
import java.util.SortedMap;
import java.util.Collections;

/**
 * The database of ClientRecords.
 * Uses a TreeMap (for now) as the data structure,
 * and ClientRecords as the nodes.
 *
 * @author W. Taff and P. Salevski
 *
 */
public class ClientDatabase {


   ////////////////////////////////////////
   //DATA MEMBERS
   ////////////////////////////////////////


   /**the database data structure of ClientRecord*/
   private SortedMap< String, ClientRecord > dbase =
      Collections.synchronizedSortedMap(
            new TreeMap< String, ClientRecord >() );

   ////////////////////////////////////////
   //METHODS
   ////////////////////////////////////////


   /**
    * Constructor for ClientDatabase
    *
    * */
   public ClientDatabase () {

   }
```

```
   /**
    * Creates a record in the database.
    * @param hostID - uid_host of the host we are creating (used as
key)
    * @param ccIn  - the calling Client Communicator
    * @return True if successfully created
    * */
   public Boolean createRecord(String hostID, ClientCommunicator ccIn){
      ClientRecord newRecord = new ClientRecord(ccIn, this);


      try {

          dbase.put(hostID, newRecord);

          System.out.println("Added record for " + hostID);

      }

      catch (ClassCastException cce) {

          System.err.println(cce);
      }

      catch (NullPointerException npe) {

          System.err.println(npe);
      }

      return true;

   }









   /**
    * get a client record from the database.
    * Pulls an instance of ClientRecord from the database, for use as
    * a helper function for class functions.
    * @param hostID - uid_host of the host of interest
    * @return ClientRecord
    *
    * */
   public ClientRecord getRecord(String hostID) {
      // gets the record from the TreeMap that has the hostID key
      ClientRecord tempClientRecord = null;
      try {
         tempClientRecord = dbase.get(hostID);
      }
      catch (ClassCastException cce) {
```

```
        System.err.println(cce);
    }
    catch (NullPointerException npe) {
        System.err.println(npe);
    }
    return tempClientRecord;
}



/**
 * Returns String of all database inbox and status for all MM-C.
 * Typically used for console troubleshooting.
 *
 * @return returnString, a string of all db parameters by client
 */
public String getAllrecordsFromDB(){

   String returnString = "";

   for (String keyString : dbase.keySet() ) {

      returnString += keyString + "," +
         dbase.get(keyString).getUID_ExerciseNetwork() +"," +
         dbase.get(keyString).getClientInbox() + "," +
         dbase.get(keyString).getClientStatus() +"\n" ;

   }//end for-loop


   return returnString;

}




/**
 * deletes a client record from the database.
 * Will attempt to remove a client record from the database,
 * based on the host UID provided.
 * @param hostID - uid_host of the host of interest
 * @return True of record and deleted, False if record not found
 *
 * */
public Boolean deleteRecord(String hostID) {

   // tries to delete the record
   Boolean deleteSuccess;

   ClientRecord tempClientRecord = null;

   try {

      tempClientRecord = dbase.remove(hostID);
```

```
   }

   catch (ClassCastException cce) {

       System.err.println(cce);
   }

   catch (NullPointerException npe) {

       System.err.println(npe);

   }

   if (tempClientRecord == null)

      deleteSuccess = false;

   else {

      deleteSuccess = true;
   }

   return deleteSuccess;

}

////////////////////////////
// UPDATE (SET) METHODS
////////////////////////////



/**
 * Halts running module - OVERLOADED METHOD.
 * Called without arguments, halts running module in all
 * modules.  Simple iteration over dbase, setting client
 * inboxes to HALT.
 */
public void halt_module(){

   for (String keyString : dbase.keySet() ) {

      dbase.get(keyString).setClientInbox( "HALT" );

   }//end for-loop


}//end halt_running_mods()
```

```
   /**
    *    Starts running module - OVERLOADED METHOD.
    * Called without target arguments, starts running module in all
    * modules.  Simple iteration over dbase, setting client
    * inboxes to MOD_X, where X is the module number.
    *
    * @param moduleNumber
    */
   public void run_module(int moduleNumber){

      for (String keyString : dbase.keySet() ) {

         dbase.get(keyString).
            setClientInbox("MOD_" + moduleNumber);

      }//end for-loop

   }// end run_module()




}
```

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APPENDIX F. MM-SERVER: CLIENTRECORD.JAVA

```
package commandserver;
// Filename: ClientRecord.java
// 21 December, 2010

/**
 * ClientRecord - the records in the database.
 * Includes all fields associated with a single client, except for
 * it's uid, which the record is keyed by in the database.
 * @author W. Taff and P. Salevski
 *
 */
public class ClientRecord {

   ////////////////////////////////////////
   //DATA MEMBERS
   ////////////////////////////////////////



   /**unique identifier of the exercise network */
   private String uid_ExerciseNetwork;


   /**status of the client, set by the client, read by server */
   private String status;


   /**inbox of the client, set by server, read by client */
   private String clientInbox;

   /**where the ClientCommunicator lives */
    private ClientCommunicator cc;
```

```
   ////////////////////////////////////////
   //METHODS
   ////////////////////////////////////////



   /**
    * Constructor for a ClientRecord - called by ClientDatabase.
    * Gets passed hostID, exerciseID and a socket.  Initializes
    * the class with the passed params, and makes empty for those
    * params that it does not yet have.
    * @param hostID - uid_host of host we are creating (used as key)
    * @param exerciseID - the UID of the exercise
    * @param passedCC - the ClientCoummincator for the client.
    * @param db - the database of clients
    */
   public ClientRecord (ClientCommunicator passedCC, ClientDatabase
db){ this.cc = passedCC;

      this.uid_ExerciseNetwork = "NOT_SET";

      this.status = "INITIALIZED";

      this.clientInbox = "INITIALIZED";

   }



   ////////////////////////////
   // GET METHODS
   ////////////////////////////


   /**
    * returns the content of the client's inbox
    * The client inbox is set by the server, but read by
    * the client.  Consists of a plain text string value.
    * @return clientInbox - the contents of the client's inbox
    */
   public String getClientInbox(){

      return clientInbox;

   }


   public ClientCommunicator getCC(){

      return this.cc;

   }
```

```
/**
 * for the commandServer to get status of the individual client
 * @return status - the contents of the client's status box
 */
public String getClientStatus(){
   return status;
}







/**
 * return the UID of the exercise network
 * @return uid_ExerciseNetwork
 */
public String getUID_ExerciseNetwork() {
   return uid_ExerciseNetwork;
}




////////////////////////////
// SET METHODS
////////////////////////////




/**
 * Allows server to write message to client inbox.
 * Only servers shall write to the client inbox.
 * @param hostID - uid_host of the host of interest
 * @param message - String of message FROM server TO client.
 * */
public void setClientInbox(String message){

   clientInbox = message;

}
```

```
    /**
     * Allows client to set their status in status box of record.
     * Only clients shall write their status to their status box.
     * Read by the server to ascertain status of the client.
     * @param message - String of status FROM client.
     *
     * */
    public void setClientStatus(String message){

       status = message;

    }







    /**
     * Allows client to set exercise in exercise field of record.
     * Only clients shall write their exercise to their exercise
     * field.  Read by the server to ascertain exercise of the client.
     * @param message - String of exercise FROM client.
     *
     * */
    public void setExercise(String message){

       uid_ExerciseNetwork = message;

    }


} // end of ClientRecord class
```

APPENDIX G. MM-CLIENT: CLIENTPROGRAM.JAVA

```
/*************************************************************/
/*                                                           */
/*      Program:  Malware Mimic Client                       */
/*                                                           */
/*      Handles client side communications.  Controls session*/
/*      with remote server.  Executes commands from server on*/
/*       local machine.                                      */
/*                                                           */
/*      FILE:       ClientProgram.java                       */
/*                                                           */
/*      USAGE: ./MM-Client hostname exerciseId srvrName srvrPort*/
/*                                                           */
/*          hostname      name of host                       */
/*          serverName    IP addr of server, in dotted quad  */
/*          serverPort   Integer port number of remote server*/
/*                                                           */
/*       AUTHORS: W. Taff and P. Salevski                    */
/*                                                           */
/*       DATE: 22 January 2011                               */
/*                                                           */
/*                                                           */
/*************************************************************/

package mimicClient;


/**
 * The MM-Client software for remote host.
 * Handles both sides of  communication with the remote server
 * (up and down) as well as local execution of remotely (server)
 *  commanded methods.
 *
 * @author W. Taff and P. Salevski
 *
 */
public class ClientProgram {
```

```
/**
 * Top level main() for program.
 * Loops, starting clientController with each iteration.  If
 * clientController dies, handles that exception, and restarts.
 * So far, is self perpetuating - i.e., will loop until killed
 * externally.
 *
 * @param args hostName, exercise Id, server IP.addr, server port
 */
public static void main(String[] args) {



   while (true) {

      try {

         new ClientController(args[0], args[1], args[2], Integer
               .parseInt(args[3])).run();

      } catch (NumberFormatException e) {

         e.printStackTrace();

         System.out.println("Check your parameters!\n" +
               "Expect hostId exerciseID serverIP.addr " +
               "serverIP.port" );

         System.exit(2);

      }

      catch (ArrayIndexOutOfBoundsException e) {

         e.printStackTrace();

         System.out.println("Check your parameters!\n" +
               "Expect hostId exerciseID serverIP.addr " +
               "serverIP.port" );

         System.exit(2);

      }

      catch (NullPointerException f) {

         f.printStackTrace();

      }

      catch (Exception e) {

         e.printStackTrace();

      }
```

```
         finally {
            try {
               Thread.sleep(10000);
            } catch (InterruptedException e) {
               e.printStackTrace();
            }
         }
      }//end while
   }// end main()
}//end Class
```

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APPENDIX H. MM-CLIENT: CLIENTCONTROLLER.JAVA

```
package mimicClient;

import java.io.*;
import java.net.InetAddress;
import java.net.Socket;
import java.util.Random;

/**
 * Controller class for the Malware Mimic client.
 * Started by ClientProgram. IPC code based on code by
 * John Yeary.
 *
 * @author W. Taff and P. Salevski
 *
 */
public class ClientController {



   ////////////////////////////////////////
   //DATA MEMBERS
   ////////////////////////////////////////

   private String hostName;

   private String os_name;

   private String exerciseID ;

   private Runtime localRuntime;

   private String status;

   private InetAddress localMachine;

   private Socket socket;

   private String textReceiveBuf;

   private BufferedReader inBufferedReader;

   private PrintStream outPrintStream;

   private String serverAddr;

   private int serverPort;
```

```
//////////////////////////////////////////
//METHODS
//////////////////////////////////////////

/**
 * Constructor for ClientController
 * @param serverPort the port of the remote server to use
 * @param serverAddr the string dotted-quad server address
 * @param hostName the hostname of local machine; will append
 * @param exerciseID
 * @throws Exception
 *
 */

public ClientController(String hostName, String exerciseID,
      String serverAddr, int serverPort) throws Exception {

   super();

   os_name  = System.getProperty("os.name");

   localRuntime = Runtime.getRuntime();

   status = "READY";

   localMachine = InetAddress.getLocalHost();

   socket = new Socket(serverAddr,serverPort);

   this.hostName = hostName + localMachine.getHostName();

   this.serverAddr = serverAddr;

   this.serverPort = serverPort;

   this.exerciseID = exerciseID;

}




/**
 * Main body of the clientController.
 * Loops until receives a halt command, checking the inbox
 * located on the remote server, and executing any commands.
 *
 * @throws Exception
 */
public void run() throws Exception {

   initializeConnection();

      //and then start looping and keep checking inbox
      while ( textReceiveBuf.compareTo("HALT")!=0 ){
```

```
         outPrintStream.println("GETINBOX");

         Thread.sleep(5000);

         textReceiveBuf = inBufferedReader.readLine();

         System.out.println(textReceiveBuf);


         if ( textReceiveBuf.compareTo("MOD_0")==0 ) mod_0();

         if ( textReceiveBuf.compareTo("MOD_1")==0 ) mod_1();

         if ( textReceiveBuf.compareTo("MOD_2")==0 ) mod_2();


      }//end while


      //CLOSE CONNECTION
      outPrintStream.println("CLOSING...");

      Thread.sleep(1000);

      socket.close();


}//end run()









/**
 * Initializes the connection with the remote host.
 * Called by run(), connects with the remote host, and upon
 * connection, sends initialization parameters to the server.
 *
 * @throws Exception
 */
private void initializeConnection() throws Exception {

   System.out.println("Connected ... waiting for #GETNAME") ;

   outPrintStream = new PrintStream(socket.getOutputStream() );

   inBufferedReader = new BufferedReader(
            new InputStreamReader(socket.getInputStream()));

   //GIVE TIME FOR INITIAL COMMAND TO ARRIVE
```

```
   Thread.sleep(1000);


   if (inBufferedReader.ready()) {

      textReceiveBuf = inBufferedReader.readLine();
      System.out.println(textReceiveBuf);

   }

   //if server says getname, tell it

   if (textReceiveBuf.compareTo("#GETNAME")==0 ){

      outPrintStream.println("NAME=" + hostName);
      outPrintStream.println("STATUS=" + status);
      outPrintStream.println("EXERCISE=" + exerciseID);

   }


}// end initializeConnection()









/**
 * A hping scan of 10 sequential ports from a random start port.
 * Scans server in range of 1 to 1024.
 * @throws InterruptedException
 */
private void mod_2() throws InterruptedException {

   status=("MOD_2");

   outPrintStream.println("STATUS=" + status);

   int randomPort = new Random().nextInt(1014) + 1;



   try {

      Process p = null;

      if (os_name.contains("Linux")) {

            p = localRuntime.exec("/usr/bin/sudo " +
                  "/usr/sbin/hping3 -c 10 -s 1 -p "+
                  randomPort + " -S " + serverAddr);
```

```
            randomPort++;

            System.out.println(randomPort);

      }

      else { //is windows


            p = localRuntime.exec("hping -c 10 -s 1 -p "
                  + randomPort +" -S "+serverAddr);

            System.out.println(randomPort);

      }


   } catch (IOException e) {

      e.printStackTrace();

   }

   System.out.println("Mod 2 Iteration Complete");


}//end mod_2()




/**
 * A 5 ping module.
 * Pings server 5 times then stops.
 */
private void mod_1() {

   status = "MOD_1";

   outPrintStream.println("STATUS=" + status);


   try {

      Process p;

      if (os_name.contains("Linux")) {

         p = localRuntime.exec("/bin/ping -c5 " + serverAddr);

      }

      else { //is windows
```

```
            p = localRuntime.exec("ping -n 5 " + serverAddr);

         }

         BufferedReader buffRdr = new BufferedReader(
               new InputStreamReader(new BufferedInputStream(
                     p.getInputStream())));

         String line;

         while ((line = buffRdr.readLine()) != null) {

            System.out.println(line);

         }

         try {
            if (p.waitFor() != 0) {

               System.err.println(
                     "exit value = " + p.exitValue());
            }
         }
         catch (InterruptedException e) {
            System.err.println(e);
         }


      } catch (IOException e) {

         e.printStackTrace();

      }

      System.out.println("Mod 1 Iteration Complete");


   }//end mod_1()


   /**
    * Sends a status update message to the server.
    * Equivalent to an idle command.
    *
    */
   private void mod_0() {

      status=("MOD_0");

      outPrintStream.println("STATUS=" + status);

   }  //end mod_0()


}// end class
```

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