

Pollination in MAIDS: Detecting and Combating Passive Intrusions in a Multi-agent System

Jeremy Kackley
Noetic Strategies, Inc
P.O. Box 22225
Huntsville, AL 35814
jeremy.kackley@gmail.com

James Jacobs
Jackson State University/CDID
1230 Raymond Rd.
Jackson, MS 39204
jjacobs@c-did.com

Paulus Wahjudi
Weisberg Division of
Engineering & Computer
Science
Marshall University
Huntington, WV 25755
wahjudi@marshall.edu

Jean Gourd
Louisiana Tech University
Center for Secure Cyberspace
P.O. Box 10348
Ruston, LA 71272
jgourd@latech.edu

ABSTRACT

In our previous work [1], we introduced a Multi-Agent Intrusion Detection System (MAIDS) aimed at detecting attackers through the observation of anomalous data. When detecting attacks that originate from passive nodes (that essentially just observe), relying upon anomalies presents a major weakness. In this paper, we extend our framework by integrating a novel process we call *pollination* that allows for the traceback of an agent's path in the network by leaving evidence of migration on both the agent and the node. As this work is fairly new, we provide a high-level overview and discuss how such a process might work within the context of our framework in order to detect passive attackers.

1. INTRODUCTION

In our previous related work [1], we introduced a mobile agent infrastructure that assisted in detecting and combating compromised network nodes. A weakness in this infrastructure is the inability to detect compromised nodes that are passively intercepting information.

The ability to identify passive attackers, compromised network nodes, compromised agents and/or systems in the Detecting and Combating Compromised Platforms (DCCP) framework requires the ability detect anomalies and/or changes in the mobile agent network and associate these changes with a specific threat. Several techniques exist in the mobile agent research community to eliminate the ability of the network to change by hardening the network (examples) [2]. Other techniques rely on the ability to detect, trace and eliminate

the anomalies in either the network or the agents (examples) [3].

Much of the existing research in mobile agent security is focused on hardening the agent or the agencies against attack (examples) [4]. The focus is primarily on encryption or encapsulation techniques to harden the agent or agencies from attackers. The problem with encryption or hardening techniques is that they only buy time before the information is decoded or vulnerabilities develop thereby compromising the mobile agent network. The general technique to buy extra time is to change the defensive strategy more quickly than the time it takes to compromise the system. The problem with this approach is the inability to detect a failure in the defensive system in a timely manner. For example, a passive node could simply collect data for a period of time long enough to break the defense and after which have little chance of being detected.

Other techniques for mobile agent protection rely on identifying and eliminating the threat. For example, (author) in [5] introduces an identification mechanism that watermarks the agent or the transmission of the agent and (author) in [6] marks the agent with packet tags. These mechanisms can be used to passively identify the movements of agents by following the traces they leave in order to reconstruct a path back to the source of the anomaly.

The problem with these techniques is one of limited focus in that they do not look at patterns found in the entire network. They merely compare changes of individual instances. In order to address passive nodes, the ability to ascertain changes in agents, the movement of agents, agencies, and the intent of agencies must be considered.

Further tracking requires active involvement and transmission of activity to determine a mobile agent's status [7]. Although the active tracking does give a better picture of the mobile agent network status, the active scheme mandates communication overhead.

1.1 Pollination

The proposed pollination scheme in this work is a passive system that allows minimum overhead with active monitoring to provide near real-time discovery of the mobile agent networks status. Pollination involves the exchange of pollen between the mobile agent and the agency to provide a tracking and a pattern mechanism for use with inference modeling. The pollen allows for tracking an individual agent's movements and intentions, and the pollination patterns in both the agent and the agency allow for network and agency status to be inferred. The inference model then classifies the intent, and the security protocols in DCCP will be enacted based on the perceived intent. Scaling of the pollination model allows for overhead to be minimized to the level of the threat.

The concept of pollination is designed to create a series of trail markers on both the nodes visited by a mobile agent and the mobile agent itself. The trail markers allow immediate identification of what nodes the agent has visited by simple inspection of the pollen the agent is carrying. The location of the node inspection is trivially the agent's destination (last location), and by traversing the trail of pollen back to the source node one can trace the agent's migration history.

The information provided by pollination is meant to be both historical and active. Historical information can be used to determine the sequence of events after an event has occurred. Active information is obtained from real time inspection and is used to determine if an event has occurred. For example, in many cases the data and the code that processes the data by themselves are not sensitive. However, the ability to obtain both the data and the code has the potential to cause harm to the agent's owner or designer. If both nodes are marked and each node in the network is sensitive to this situation, a mobile agent containing pollen associated with both nodes can be apprehended.

Security in information system is an important aspect for all applications that covers three main components: data security, machine security and network security. One of the key issues involves the authentication of an entity in relation to its access to various resources. A trusted entity may become compromised, and thus untrustworthy, despite being positively identified. Determining if an entity has been compromised is an important but complicated process. This paper introduces the pollination concept that extends our DCCP framework's capability to detect compromised platforms that passively intercept information.

2. FRAMEWORK OVERVIEW

Our work introduced in [1] presented DCCP, an agent based framework for detecting compromised platforms. The key aspect of this framework is the concept of threat levels, and it provides an effective method to detect and combat compromised platforms. Threat levels correspond to a global view of how dangerous the situation is, as well as a controlling factor for the operation of the framework. These levels range from *Threat Level One*, which can be considered "situation normal" and where strictly passive observation occurs, to *Threat Level Four*, where action is taken against suspected nodes. The progressive network threat levels allow for dynamic and adaptive detection with varying degrees

of response. Once a platform is suspected of being compromised, the node (and any nodes that comes in contact with it) will be thoroughly investigated before any verdict is given. Depending on the algorithm used to observe the network traffic, DCCP can be adapted to observe the smallest piece of data or it can focus the network as whole. However, DCCP is dependent on one key element: the active data packets sent by the compromised platform that the framework can then intercept and detect for irregularities. In the event that a compromised platform is passive and focuses only on intercepting information routed through it without actively sending packets to other nodes as an attempt to obtain information and/or to infect other nodes, DCCP will never suspect that node as being compromised. This weakness will be addressed in this paper through the utilization of a Mobile Agents Pollination (MAP) technique.

2.1 Threat Level One: Network Observation

This corresponds to situation normal and is the default threat level. The key action that takes place at this threat level is establishing and maintaining a network of "probe" agents. These probes can be thought of as a distributed set of eyes and ears. This threat level also sees the establishment of a Central Authority Node (CAN). This node serves as the nerve center of the framework; as agents percolate through the network they carry reports generated by the probes. These reports are ultimately carried to the CAN which makes judgements based upon them. In this way, the CAN can monitor and maintain a somewhat out-of-date view of the entire network at a relatively low cost to performance. This view can be used to search for anomalies, such as a disproportionate number of agents arriving to those leaving a given node. Anomalies are domain-dependent. A certain level of anomalies is expected as a by-product of network behavior, thus a threshold value T_1 is defined that indicates the maximum amount of anomalies to be expected in a non-compromised network. Rates above this value would constitute an elevation of the threat level.

2.2 Threat Level Two: Network Suspected Compromise Investigation

At this threat level the network is suspected to be compromised. This triggers the CAN to generate two agent types: a Commander agent and a Detective agent. Commander agents are akin to a localized CAN, the purpose of which is to reduce report latency. Detective agents are proactive versions of the probes that communicate observations directly to their Commander agent. The concept is to blockade the suspected node or nodes and investigate incoming and outgoing traffic to see if the anomalies are still occurring greater than the threshold value. There is a network effect whereby any nodes that can only communicate through a suspected node are of course also suspect and cannot be trusted; thus, the virtual blockade could indeed comprise a major section of the network. The CAN takes into account this network effect when placing Detective agents so as not to compromise the aggregate data. Another important point is that this is merely an investigative roadblock; communication is investigated and monitored but is not stopped. Again, anomalies are domain dependent, but it makes logical sense that there would be more types of anomalies defined at this level. Additionally, T_2 is the second threshold value of anomaly de-

tection prior to elevation to the third threat level.

2.3 Threat Level Three: Network Compromise Confirmation

This threat level sees the creation of an additional type of agent, the Secret agent, that is essentially something of a sacrificial agent. Its actions (and the expected results thereof) are predefined; therefore, it can be sent to a compromised node, and if the results are not observed exterior to the node or the communication of its observed effects do not match the observations of Detective agents, then an inference can be made that a compromise has occurred. It is possible that the Secret agent would never be heard from again, in which case this process must be repeated until either the agent survives or a set number of agents have been sacrificed. It is also possible at this threat level to either elevate to Threat Level Four, or to deescalate if the Secret agent is not interfered with.

2.4 Threat Level Four: Network Compromise Resolution

For the most elevated threat level, the assumption is that a compromise has occurred. There are a variety of actions that can be taken at this point. The appropriate action is very domain dependent; for example, if resource availability is more important than information security then simply alerting a human while continuing to gather information is the appropriate response. Alternatively, if information security is more important than availability or redundant resources exist, then automated responses are possible. The least severe response would be rerouting requests from the compromised node to a sandbox for future analysis and to prevent the compromise of the rest of the network (presumably without making it obvious to the attacker that he has been detected). A more severe action would be to blockade that node from the network preventing any requests from leaving or going to that node. The most severe would be attempting to remove that node from the network and/or crash it such as via a distributed denial of service attack or some out of band signal.

3. MOBILE AGENTS POLLINATION

Mobile Agents Pollination (MAP) is a concept that addresses some of the issues with the DCCP framework, namely that of detecting passive attacks, by identifying a mobile agent's movement and actions within the network. MAP uses *pollen* to uniquely identify the agencies or groups of agencies within a network. Furthermore, MAP uses pollination to form a trail map defining the path an agent utilized when visiting the agency nodes. In addition to the trail map, the pollen and map properties can be utilized as action indicators to infer the meaning of the agent's visitations and the agencies' intent within the network.

MAP is similar to the natural process of flower pollination by bees. Bees traverse a field of flowers to acquire nectar. The bee stops at each flower and inadvertently collects pollen and distributes pollen to the flower. A pollen grain represents a flower and a collection of pollen on the bee represents all the flowers the bee has visited. The pollen collection left by the bee at each flower represents the sequence of flower visitations before acquiring nectar at the current flower. The

analogy follows for MAP with the mobile agent as the bee, the nectar as the information (data) and the pollen as an identification marker of a particular agency node. The role of the mobile agent is to traverse the network of connected nodes to acquire information. MAP defines the process where the mobile agent inadvertently collects pollen from the current node and distributes pollen from the previous nodes visited. The pollen can then be used to quickly map where the mobile agent has traveled and the sequence of travel. Other traits related to the map, the pollen, and the pollen's relationship to the node can be utilized to expand the perceptibility of the mobile agent's activity in the network.

The main purpose of MAP is to utilize pollination for tracking a mobile agent's activity in the network and use this tracking information to infer the intent of the mobile agent and the agencies involved in the network. Pollen is a marker used to identify a specific node a mobile agent may visit. Pollination is the process of exchanging pollen to provide a mechanism to reconstruct where the agent has been and infer the actions the agent performed.

Pollen can be unique to each node or the pollen can be unique for a subset of nodes depending on user requirements. The pollen variation throughout the network is similar to the DNA of a flower. The DNA for a specific node type is mostly the same between entities with minor variations making the sequence unique. The pollen from two different node types will have a greater variation in the predominating factors. The pollen strictly provides the identification for a node and should be dependent on the agency configuration to make the process of spoofing an agency difficult. The information provided by pollination is meant for both historical and active analysis. Historical information can be used to determine the sequence of events after an event has occurred. Active information is used to form real time inspection in order to determine if an event has occurred.

The two key observable parameter categories involved in the process of a mobile agent collecting information from the agencies are spatial and temporal. The space for MAP refers to the network space in the direction used by the node, the connection, the mobile agent, and the pollen. The spatial category could be expanded to include distance for the connection and the agent's travel; however, at this time it is unclear on the usage and necessity of the metric.

The network's spatial reference is depicted using standard network nodal reference with connections showing the relation between the nodes. The pollen associated with the nodes and the agents is represented by unique patterns. The pollen grains carried by the mobile agent and distributed to the agencies maintain the pattern of the origin node. The sequence of pollen grains creates a series of trail markers which define the spatial movements of the agent through the network. A direction depicted by the arrow is inherent in the sequence as the agent migrated from the preceding nodes to reach the current node. The pattern allows immediate identification of what node(s) the agent visited by simple inspection of the pollen the agent is carrying. Traversing the trail of pollen defined by the sequence will lead back to the source node.

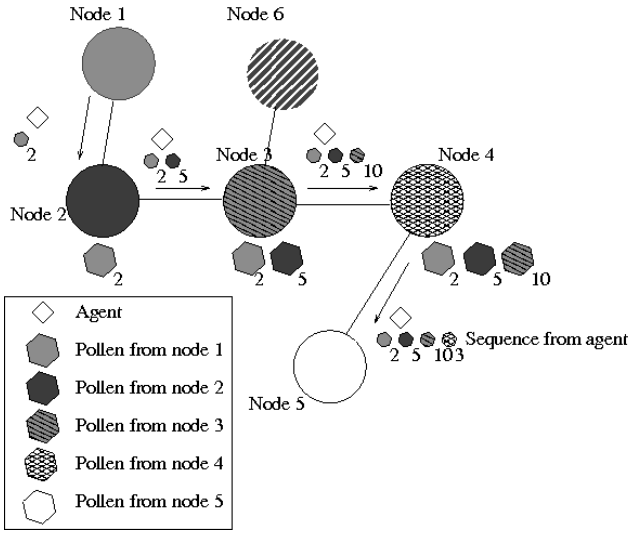


Figure 1: Pollination and Mobile Agents

The time for MAP is used to refer to the amount of processing the mobile agent expended at the node in terms of number of pollen grains. The number of grains refers to the action time of the agent, such as time spent, data examined or a ratio of time spent to data examined. The number is associated with a grain of a specific node and the combination of all the grain counts will indicate the time taken for the sequence to complete. A common time reference will maintain a standard gauge for use with the analytics. The actual time interval is up to the implementation; however, the granularity of the interval should represent the difference between operation actions of the mobile agents for the operations we want to identify. The temporal reference is depicted by a count below the grains.

We acquire a time-sequence pattern by applying both the spatial and temporal components. The time-sequence pattern maps the networks meaning to the goal of the mobile agent's movement. The spatial, temporal and spatial-temporal observations are used to infer the meaning of the action with regard to the intent of the agent and nodes. Associating the content description of the nodes with the pattern may allow for further identification of a mobile agent's actions.

The process of pollination leaves two distinct time-sequence trails as the mobile agent moves from node to node. The first trail is the set of pollen attached to the agent from the simple process of visiting nodes. The second is the set of pollen distributed along the path of nodes traveled where each node has a snapshot of the previous places the agent has been. The sets have a number of key attributes that include node references, number of pollen spores, sequence of spores and the order (pattern) of nodes visited, and amount of pollen attached. The pollination concept is depicted in Figure 1.

In this figure, an agent is migrating from Node 1 to Node 5. At each node, the agent exchanges pollen with the agency in the process of "doing work." The amount of work is quantified with the temporal reference. The agent reaches Node 5,

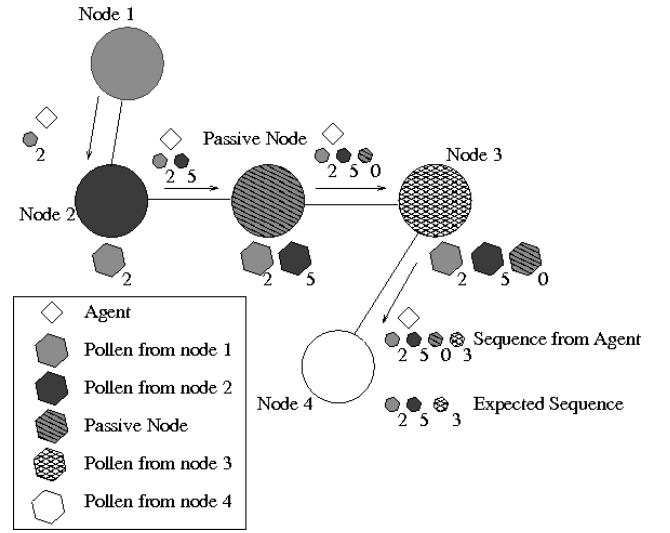


Figure 2: Network with Passive Node

and the resulting pattern is depicted with the temporal references denoted by the vector $\langle 2, 5, 10, 3 \rangle$. Note that Node 6 is not in the agent's path and therefore no pollen is exchanged with this node or the agent. This example serves as a base pattern or a composite of patterns that can be used to determine anomalies that occur with the agent's or node's standard operation.

3.1 Usage for DCCP

In order to address the passive attack we simply have analytics to infer the meaning of the change in pattern. Suppose, for example, that we have a passive node that inserts itself into the network. The node will have to understand that pollination occurs otherwise it will not be accepted. We assume the attacker is smart enough to spoof a node and continue with more advanced security concerns.

Suppose we mark the path agents would take from Node 1 to Node 4 (in Figure 2) by marking each of the intermediate nodes with different pollen. Every time an agent reaches Node 4, it possesses a sequence of pollen that corresponds to the path taken. This is verified with the sequence that the agent was supposed to follow in order to determine if the agent has been compromised by an additional passive node or a violation of the agent code. The passive node is identified by added pollen, incorrect pollen or the lack thereof in the sequence inspected at the end point. A team of Commander and Detective agents can be used determine which node is the passive node and eliminate it. Compromised agents can simply be eliminated from the system at Node A or Node B (why the letters instead of numbers?) on arrival and trigger the inspection. For added security, every node along the path checks the pollen sequence and essentially provides a passive defense mechanism against corruption.

3.2 Implementation

The pollination process works at the application level where the agencies represent the nodes and mobile agents move throughout the network migrating from agency to agency. The agencies each have their own unique pollen definition.

Implementing the pollen requires the ability to attach pollen and transport it with the mobile agent; it is *picked up* and *dropped off* by the agencies. We propose that the process of attaching the pollen to the mobile agent is not performed by the agent itself in order to stick with the inadvertent nature of pollination (?). The agent should not know or care about the pollination. We envision the use of the manipulation of the Open System Interconnection (OSI) [] model's transport layer for both attaching the pollen to the agent and transporting the pollen and agent to the destination node. In the OSI model the application data to be transported is broken into packets and transmitted from the source to the destination. We can add additional packets by appending the pollen to the data stream, or we can manipulate the packets using packet tagging. Adding additional packets can be accomplished at the application level by simply appending to the end of the mobile agent in that data stream. The addendum is removed at the agency and the pollen is recovered.

Packet tagging is accomplished by marking packets with identifiers for local purposes []. The actual mark is part of the packet and cannot be removed; however, the mark can be modified or replaced with another mark. This maybe an issue if the agent is transmitted to some location that is external to the system. However, for our purposes the mobile agent is assumed to remain internally within the network.

In addition to the pollen tag itself, the count representing action at each node is used to acquire further insight into the meaning. It is expected that a node with little information to share will require less time for the mobile agent to visit the node (i.e., less activity). Using the activity gauge, we can infer some of the intent of both the agent and the agency. In the example of a passive node scenario, we can expect the sharing to be minimal for the agent (as described by the label "0" in Figure 2) with regard to the passive node's pollen.

The reverse is also possible with the relationship between the node pollen and the data stored at the node. Using this relationship between the information of the node with the highest activity, we can infer the type of information the agent is interested in gathering and the information with little interest. The entire concept is depicted in Figure 2.

The purpose of pollination is to allow an easy identification method for activity within a mobile agent environment using pollination patterns. Any standard inference model (e.g., fuzzy logic, neural network, Bayesian model) can be utilized to trigger DCCP security events from the pollination patterns.

A variation of the scheme can be implemented to acquire different levels of security through the network. At a low level we are only concerned with sensitive data or applications. For this level we simply need to pollinate those locations and track the movement of agents carrying that pollen. Agencies are always active to interpret the meaning of the mobile agents and the surrounding agencies. The limitation of the pollination to a subset of the network has the effect of greater focusability on only the things that matter. It also reduces the overhead associated with pollination in both time and space.

We can change the pollination patterns associated with the network on a periodic basis to ensure security. This change can either be notified to the DCCP security team in advance or the change could simply trigger an event that allows the team to determine the appropriate action. The latter is preferable as the addition of a mechanism to disable security for changing patterns could be an exploitable vulnerability. The event triggered by the pattern change can be used as a test of system integrity as the process goes through the security levels and back to Threat Level 1.

The standard state of the system is primarily in Threat Level 1; however, as security concerns increase, the number of pollinated nodes increase to match the threat. The increase can either be tactically focused on the relative sensitivity of the data or the increase can be distributed throughout the network to provide a "big picture" of the secured environment. At the highest level all nodes will be pollinated, and nodes without pollen or agents not containing pollen will be apprehended. The pollination paths not adhering to the required patterns will be examined to determine what events took place by the DCCP security agent team.

3.3 Detecting passive compromised nodes with pollination

Once pollination is in the framework, we can then proceed to setup a set of traps that will assist in detecting compromised passive nodes. The purpose of the trap is to lure passive nodes to actively search for prized data that, in turn, will expose their cover. The CAN will randomly select a set of strategic nodes of interest (SNI) throughout the network as the host of the prized data. Each trap will have a designated area of effect that determines the number of nodes that are affected. CAN will then send agents to each node with the objective of broadcasting the existence of crucial data in the SNI. The CAN will then observe network activities and validate the pollen of every agent that visited the SNI. When an invalid pollen pattern is found, CAN will then raise the network situational awareness to Threat Level 2 and then proceed to investigate the path taken by the agent to reach the SNI. Every node that the suspected agent came in contact with will then be considered a suspected compromised node. The Commander agent and Detective agents will then proceed the investigation to confirm whether a node is compromised through Threat Level 3.

4. MOLE EXAMPLE

Blah.

5. CONCLUSION AND FUTURE WORK

The DCCP framework provides the ability to detect, investigate and deal with compromised hosts utilizing a multi-agent scheme in an effective and efficient network intrusion mechanism. However, DCCP relies heavily on nodes that actively attempt to obtain data that they are not entitled to and tipping their hand in the process. In the event that an intruder remains passive and only collects data that it unwittingly came across, DCCP will be unable to detect it. To cover such deficiency, we incorporate pollination into DCCP which provides the ability to detect passive attackers. As an added bonus, pollination also provides additional forensic capabilities to DCCP (e.g.?).

The role of the pollen can be expanded to include additional functionality. For example, a heavy burst of pollen issued in short intervals can affect a compromised node, thereby rendering it ineffective and possibly shutting it down or forcing the node to restart which could purge the compromising elements. Another plausible feature is the pollen's ability to affect an agent's functionality or to modify the data it collects rendering it useless. A predetermined set of pollen "colors" could have different hidden emergency messages that can be relayed by each host to the CAN. This simple coloring scheme can act as a silent alarm that notifies the CAN for a possible breach in one or more nodes.

and fault tolerant capabilities. In *Advance Computing Conference, 2009. IACC 2009. IEEE International*, pages 992–996, march 2009.

6. REFERENCES

- [1] B. Al-Duwairi and G. Manimaran. A novel packet marking scheme for IP traceback. In *Parallel and Distributed Systems, 2004. ICPADS 2004. Proceedings. Tenth International Conference on*, pages 195–202. IEEE, 2004.
- [2] A. Belenky and N. Ansari. Tracing multiple attackers with deterministic packet marking (DPM). In *Communications, Computers and signal Processing, 2003. PACRIM. 2003 IEEE Pacific Rim Conference on*, volume 1, pages 49–52. IEEE, 2003.
- [3] Y. Bhavani and P. Reddy. AN EFFICIENT IP TRACEBACK THROUGH PACKET MARKING ALGORITHM. *International Journal*, 2.
- [4] Y. Djemaiel and N. Boudriga. A global marking scheme for tracing cyber attacks. In *Proceedings of the 2007 ACM symposium on Applied computing, SAC '07*, pages 170–174, New York, NY, USA, 2007. ACM.
- [5] Z. Gao and N. Ansari. Tracing cyber attacks from the practical perspective. *Communications Magazine, IEEE*, 43(5):123–131, 2005.
- [6] M. Goodrich. Efficient packet marking for large-scale IP traceback. In *Proceedings of the 9th ACM Conference on Computer and Communications Security*, pages 117–126. ACM, 2002.
- [7] A. Khan, X. Niu, W. Anwar, and Z. Yong. On the security properties and attacks against mobile agent watermark encapsulation(mawe). In *Systems, Man and Cybernetics, 2008. SMC 2008. IEEE International Conference on*, pages 707–712, oct. 2008.
- [8] D. Lin and T. Huang. A mobile-agent security architecture. In *e-Business and Information System Security (EBISS), 2010 2nd International Conference on*, pages 1–4, may 2010.
- [9] D. Peng, Z. Shi, L. Tao, and W. Ma. Enhanced and authenticated deterministic packet marking for ip traceback. In M. Xu, Y. Zhan, J. Cao, and Y. Liu, editors, *Advanced Parallel Processing Technologies*, volume 4847 of *Lecture Notes in Computer Science*, pages 508–517. Springer Berlin / Heidelberg, 2007. 10.1007/978-3-540-76837-1_55.
- [10] D. Peng, Z. Shi, L. Tao, and W. Ma. Enhanced and authenticated deterministic packet marking for ip traceback. In *Proceedings of the 7th international conference on Advanced parallel processing technologies*, APPT'07, pages 508–517, Berlin, Heidelberg, 2007. Springer-Verlag.
- [11] R. Sreedevi, U. Geeta, U. Kulkarni, and A. Yardi. Enhancing mobile agent applications with security