SIMULATION RESULTS FOR SECURE AUTOMATIC ENERGY METER READING USING MOBILE AGENTS
- PART 1 -

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Intelligent and secure automatic energy meters reading and management using mobile agents can be of great importance for municipalities and energy distribution companies so as to efficiently read these meters and to decrease the number of traditional visits required by the energy company, and decreasing the number of employees used in performing this traditional time consuming and high cost work [1, 3, 5]. In this work we will start by reviewing the current technologies and techniques used in securely handling remote meter reading and management using mobile agents. A more detailed simulation results for different configurations and techniques of secure automatic energy meter reading and management systems using mobile agents will be presented and compared to traditional client-server techniques. These results will be presented in two parts, the first part will consist of OPNET simulation results for our system, and the second part will present the results of the secure system using java agent development environment (JADE) environment.

1. INTRODUCTION

A mobile agent is a program (code and data) that can migrate from host to host in a network of heterogeneous computer systems and fulfill a task specified by its owner. It works autonomously and communicates with other agents and host systems. During the migration, the agent carries its code, may be data, and some kind of execution state with it. On each host they visit, mobile agents need a special software that is named agency or host, which is responsible to execute/host agents, provides a safe execution environment, and offers several services for agents residing on this host [6]. Secure mobile agent automatic meter reader and or manager (MAMR) is clearly presented and modeled in [1, 2, 4].

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2. BACKGROUND

Meter reading and billing are among the most time consuming functions performed by municipalities and energy distribution companies. These functions have a major influence on the utilities cost, efficiency, productivity, structure and cash flow as well. Solutions based on recording readings manually, then entering it into a central billing system are time consuming, prone to errors and delays in delivering bills to customers with negative effect on cash flow. There are many methods involved in the meter reading process; this includes traditional manual methods up to fully automatic meter reading systems [5]. Traditional and state of the art Wireless, Bluetooth and Power-Line Communication (PLC) techniques can be used to provide broadband services for AMR including: xDSL, Cable Modem, Fiber-to-the-Home, Wireless, Satellite, and PLC [5, 9].

2. AMR DATA COLLECTION USING MOBILE AGENTS

Mobile agents are commonly used in distributed information-retrieval applications. Formally, the mobile agent automatic meter reader and management (MAMR) Agent Problem is defined as follows: There are \( n+1 \) energy meters \( m_i \) with embedded servers that are capable of hosting and running MAMR where \( 0 \leq i \leq n \) including the power company’s main server, \( m_0 \). A probability, \( p_i = 1 \), of being able to successfully visit meter \( m_i \) and complete the agent’s task (reading or monitoring, or other specified tasks), also \( p_i = 0 \) means that MAMR cannot visit \( m_i \) or meter \( m_i \) is not reachable. These probabilities are independent of each other. An execution time \( x_i > 0 \), is required for the agent to attempt the visit and communicate with the next power meter before moving to a meter \( m_{i+1} \) regardless of whether it is successful or not. And a time \( r_i \) where a MAMR reads and manages a meter \( m_i \), including compression, encryption/decryption, hashing, and digitally signing read information. Travel times or latencies for the MAMR to move between sites are considered for moving between meter \( m_i \) and meter \( m_{i+1} \) [1]. When the MAMR task has been successfully completed at all possible meters, the MAMR must return to the main companies server from which it started (i.e., \( m_0 \)). For meter \( m_0 \), \( p_0 = 1 \). The Mobile Agent Automatic Reader Problem is to successfully complete the reading and managing tasks [1, 4].

A tour for the mobile agent automatic reader problem consists of specifying the order in which to read the meters, namely a permutation \( <i_1, i_2, \ldots, i_n> \) of 1 through \( n \). Such a permutation is called a tour in keeping with the tradition for such problems [1, 2]. The expected time to complete the tasks and read all meters provided that all meters are reachable, for a tour \( <i_1, i_2, \ldots, i_n> \) representing an arbitrary permutation of the existing energy meters can be expressed as:
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PART 1

(1)

Formula (1) can be explained as: The first meter, \( m_{i_1} \), on the tour is always read first (this is not necessarily the first meter \( m_1 \)) and requires traveling time to be reached. Upon arrival, time \( x_i + r_i \) must be spent there for reading and monitoring and executing. The terms \( \prod_{j=1}^{z} p_{i_j} \) arise when all reachable meters in the tour with the last reachable meter is \( m_i \) and the MAMR must return to the originating server \( m_b \).

If all meters where read successfully then \( z=n \). Fig. 1 shows a possible tour done by a single MAMR (dotted lines). MAMR can be defined as a set of \( \nu \) code blocks with size \( (\sum_{i=0}^{\nu} B_{i} \) bytes of code), data and status information with size \( B_{data+state} \), then the MAMR increases in size while moving from one meter to another specially the reading information (data).
We assume that not all of the MAMR code blocks are to be transferred each time MAMR moves from one energy meter to another and only a subset of the code blocks will be requested from the source energy meter sending the MAMR. $B_{cr}$ is the size of the requesting list and $P_s$ is the probability that a code block $B_{bs}$ is requested to be transferred as requested in the transfer list. $B_{rep}$ is the size of the optional reply from $m_i$ to $m_j$. $\sigma$ denotes the selectivity of the agent, that is, how much the $B_{rep}$ is reduced by remote processing [9]. $\delta(m_i,m_j)$ is the average network delay including DNS and other networking and routing latencies. The throughput between power meter $m_i$ and the next power meter $m_j$ is $\tau(m_i,m_j)$. The MAMR can query a network status from a directory server to find latencies times and estimated throughputs, $\delta(m_i,m_j)$ and $\tau(m_i,m_j)$. One can refer to [1] for more details and step by step derivation of equation (1). This time can be compared with the time and bandwidth used in the traditional client server AMR[1]:
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\[ T_{CS} = \text{Max}\left( p_{i_k} \cdot \left( \lambda \cdot \left( \delta(m_{i_0}, m_{i_k}) + \frac{(B_{\text{req}_{i_k}})}{\tau(m_{i_0}, m_{i_k})} \right) + \lambda \cdot 2 \cdot \delta(m_{i_0}, m_{i_k}) + \lambda \cdot \left( \frac{B_{\text{req}_{i_k}}}{\tau(m_{i_0}, m_{i_k})} + B_{\text{data}_{i_k}} + B_{\text{state}_{i_k}} + \frac{B_{\text{rep}_{i_k}}}{\tau(m_{i_0}, m_{i_k})} \right) \right) \right), \quad k = 1, 2, ..., n. \]  

where \( \delta(m_{i_0}, m_{i_k}) \) represents the network delay between \( m_{i_0}, m_{i_k} \) and \( \lambda \geq 1 \) represents queuing delay factor that arises from congestion and router processing delays especially if more than one energy meter is probed for its reading. That is the time elapsed until the last meter sends its reading data to the server in the client server architecture is the time of completing the reading of all meters. This time is calculated provided that all meters where probed for their reading at the same time. This makes large bandwidth usage since all meters will be communicating with the server which increases latencies and queuing times \( \lambda \cdot \delta(m_{i_0}, m_{i_k}) \) and also the processing and response time of the server, please refer to [1] for more details. However, in the MAMR approach, the network bandwidth is free in most of the parts of the network except the path during MAMR moving from one meter to another. An interesting case where multiple MAMRs are initiated and dispatched to collect and monitor remote meters is of concern [1, 7, 8, 9].

3. AMR AND MAMR SIMULATIONS USING OPNET TOOLS

OPNET is a powerful network simulation tool that can be used to model communication systems and predict network performance [10].

3.1. MODELING THE POWER METER WITH AN EMBEDDED SERVER

There are many data units and flows in power meter embedded systems and its controlled objects. The power meter data and status dynamically change in time. A set of monitored data must be derived, processed and represented to operators and or clients. Accordingly and as far as we concerned in power meter with embedded controller modeling, and since the OPNET does not have a special model for this component a new model should be built to model the processes incorporated in these components. However and since an energy meter with embedded server can be modeled as a normal web server functionality we have used a modified version of the normal web server model used in OPNET. This model can behave as a Web, Mail, or FTP server that are capable to serve requests from other clients. This makes it easy to let each power meter communicate with
the central facility and or other meters on the same building. It should be noticed that the random data generator model can be integrated with this model so as to randomly generate the amount of consumed power data and that is fed to the controller part of that meter. Each process node in the model can be represented as a transition Finite State diagram with an entry and an exit code that is written in C/C++ [1].

3.2. SIMULATION OF BUCHAREST VIRTUAL AMR/MAMR SYSTEM

This simulation process includes: Modeling the LAN of energy meters in a building, modeling the WAN of energy meters LANs and sites and modeling the connection to the energy company and its servers. We also assume that each energy meter has an Ethernet port, and then each meter can be connected to the other meters in the same building using the traditional LAN technologies. This includes the 10BaseT, 100BaseT, wireless LANs, Bluetooth and PLC modems. In this simulation example we used the traditional LAN with 10BaseT twisted pairs to connect about 40 power meters to constitute each LAN in a block of apartments; Each 3 Blocks are connected to a 100BaseT switch to form a “SCARA” network. So this network of almost 120 power meters (each with embedded servers) falls within the standards of the LAN technologies as shown in Figure 2.

![Connecting each 3 Blocks to a switch](image)

Figure 2 – Connecting each 3 Blocks to a switch

3.3. MODELING THE WAN OF ENERGY METERS LANS AND SITES

The networking and communication system is responsible for data access between different meters with the power company offices. Different networking methods for data transmission are used; this includes telephone lines, LANs, fiber, wireless and power line. For the Wide Area Network part, the most common technology options for providing broadband services for AMR networking
includes: xDSL, Cable Modem, Fiber-to-the-Home, Wireless MMDS, Wireless-Unlicensed, Free Wireless, and Satellite, broadband over power lines (PL). In this simulation example we will use the xDSL model to route and connect the IP packets from each “SCARA” to DSLAM multiplexer that is connected to an access server. (i.e. each xDSL modem serves 3 apartments with total 120 power meters).

The access server is connected to an IP-cloud that represents the Internet medium with certain utilization and or packet loosing assumptions. It should be noted that the communication between the xDSL and the DSLAM are handled using a down-stream and up-stream channels with different bandwidths. The used up and down stream bandwidths for this example is adjusted to 64 kbps. Also each DSLAM can connect up to 32 or 64 xDSL modems, however, and for RAM limitations for the used computer that are required to simulate this example, only 5 modems are used, that is only 5 “SCARES” are connected and simulated. In our simulation we used a network of 15 “SCARES” connected to a single DSLAM modem. Only 5 of them are utilized in the simulation because of RAM limitations.

![Diagram of network and central office facility.](image)

Figure 3 – Modeling all sectors network and the central office facility.

The bandwidth of the access line used to connect the DSLAM and the access router (which can be in a branch office in each “CARTER”) is used as a leased line with DS0 bandwidth (64 kbps). The access Router has up to 16 ports and can connect up to 16 DSLAMs. A model for connecting the different Carter DSLAMs to the main Access Router in each Sector is used, only the first Carter is included in the simulation because of the RAM limitations of the simulating computer.
3.4. MODELING THE CONNECTION TO THE ENERGY COMPANY

The other part of the network is modeled to be the energy/power company LAN which has all the IT facilities to collect, process, and manage all the meters in the grid. Assumingly each meter is polled to send its data to the central office using its embedded server part. FTP, HTTP, and E-mail protocols can be used to send this data. Figure 3 shows the upper level of the whole network which connects the facilities in each sector (6 sectors). However and because of the large network and huge memory requirements only sector 1 network is really considered in the simulation process. This means that a virtual Bucharest city network is hypothetically modeled and connected with virtually 162,000 energy/power meters. However, only 600 power meters are used in the simulations because of the computer RAM limitations.

3.5. BUCHAREST AMR AND MAMR SIMULATION RESULTS

In this section the results of running the simulation to study the effect of bandwidth usage, throughput and queuing delays of the communication links will be presented. These results are taken for both FTP and E-mail communication protocols between the energy meters and the energy company which represents the traditional AMR network system. The used computer is a P4 Intel based computer with 512 Mbyte RAM. Unfortunately only partial results were taken since any enlargement of the simulated system will cause the computer system to crash with out of memories problems. However and since the modeling of the xDSL modem connection is full so the results for this section of the network is complete and can be justified as will be discussed soon.

Here we assumed that each block of apartments uses a MAMR to collect the meters data and only one meter (usually the last meter in each sub-network of 20 power meters) will send the collected data provided that the power meters in each apartment will be able to communicate with each other using the utilized LAN technology. And since 40 energy meters exists in each block of apartments then 2 MAMRs will be sending data on behalf of the 40 power meters. The bandwidth usage in the apartment LAN is of minor importance since it is usually higher than that of the WAN links used to transmit the data to the central facility unless wireless connectivity or PLC is used as the LAN technology inside the blocks or apartments.

It should be also noted that the LAN model for each apartment is used to represent the network in each apartment with 20 power meters and one of them will serve as the communication peer with the energy company, however the amount of data that should be sent from this peer power meter is 20 times larger than that of the data sent by each power meter in the case of each power meter sending its own data to the central facility.
The OPNET package uses the definition of application protocols and profiles so as to simulate the flow of packets using different realistic statistical distribution to model the real Internet data flow. In this simulation we assumed that each power meter is sending light load FTP or E-mail data since this may be the case in real meter functioning, so we assumed that each power meter sends data only once each 720 second using exponential distribution.

Figures 4 and 5 show the results of the bandwidth utilization of the link connecting the xDSL modems to the DSLAM using the E-mail and FTP protocol respectively. These figures (4 and 5) show the utilization for both all power meter sending (client-server) and 1 of 20 power meters (MAMR) sending scenarios. It is clear that using the MAMR idea reduces the bandwidth usage in the xDSL modem links. Also the results of the queuing delay for the same configurations shows clear reduction in the delay for the MAMR over client server usage in the xDSL modem links as well.

From these scenarios, the conclusion of the necessity of considering a more deep study of this system and all the parameters of the xDSL links and all other links in the system is clear. However a more powerful simulation computer and huge amount of RAM should be used.

3.6. HEBRON AMR AND MAMR SIMULATION RESULTS

In this section we will present simulation results used in modeling networks of power metering systems for part of Hebron city in Palestine as shown in figures 6 and 7. The basic elements modeling like the energy/power meter are as described.
in the previous section. Other parts modeling includes: Modeling the LAN of power meter in a site, modeling the WAN of power meter LANsWLANS or sites and modeling the connection to the energy company and its servers.

However, simulating the whole network of the city (20 parts) requires very large amount of memory, accordingly I have chosen to simulate the power meters network using 1 or 2 parts of the city with both wired and wireless (WLAN) scenarios, Figure 8. The Energy/Power company is assumed to have a T1 (DS0 1.544Mbps) Leased Line, each part of the city (~ 50-100 homes) is connected using ADSL/DSLAM (16kbps/64kbps). The houses are connected through a LAN/WLAN, Figure 9.
More than 60 simulation sceneries were considered in the simulation for Utilization (%), Throughput (packet/sec) and Queuing delay (sec) performance parameters. For example, Figure 10 shows the utilization for the DS1 link for Energy Company for one region and two regions connected.

Figure 10 shows the delay for packets passing through this link. Figures 12, 13 show the utilization and delay for the scenario where all meters are sending their readings using FTP or e-mail and compared to the case where only one meter is getting all readings and sending it on behalf of the other meters (the size of the sent data is much larger). The later case represents the MAMR idea, where the former one represents the client-server case. This case is repeated for wireless meters.

Figure 11

Figure 12

Figure 13
Figures 14, 15 show the utilization and the throughput (packets/s) of the xDSL link for both client-server and MAMR configurations.

![Figure 14](image1.png) ![Figure 15](image2.png)

Fig. 16 – Throughput of different links.
4. DISCUSSIONS AND CONCLUSIONS

In part one of this article we presented the simulation results for the mobile agent automatic meter reading systems (MAMR) using the OPNET simulation tools. In the second part secure MAMR simulation will be presented. The discussions and results of the whole article will be presented in part 2.

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