A Mobile Ad-Hoc Network Data Communication Benchmark

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Abstract - A Mobile Ad-Hoc Network is a wireless, self-organizing network where all clients and all servers are mobile and battery powered. Currently, most MANET research has been centered on data routing. Increasingly, data communication methods in MANET are being explored. A MANET allows data communication through data broadcast, data query, and peer-to-peer messages. One significant difficulty in assessing and comparing the different MANET data communication protocols proposed is the lack of a standard test environment or benchmark. A MANET data communication benchmark must include, at a minimum, a standard architecture, standard workload, and a standard set of evaluation parameters. This paper describes the major features of a MANET data communication benchmark and demonstrates the benchmark through analysis and simulation of the TriM MANET data communication protocol. This is the first benchmark targeted at MANET data communication research.

I. Introduction

Benchmarks are an accepted way to compare and evaluate different protocols, algorithms and architectures. The use of a benchmark indicates that an area of research is well established [1]. When a benchmark is introduced into a research field, benefits may include increased discipline maturity, as well as increased technical progress and collaboration [1].

Within the database community, benchmarks have been a powerful tool, providing the ability to compare and evaluate different database systems [2]. For example, a commonly accepted benchmark for transaction processing in database systems is provided by The Transaction Processing Performance Council (TPC) [3]. TPC is based on a banking debit/credit model and measures transactions per second [3].

Not every benchmark developed is for overall system evaluation. For example, Darmont developed a benchmark to specifically measure the performance of clustering protocols in OODB systems [4]. Traditional mobile computing is no different. For example, Seydim and Dunham developed a benchmark to measure the performance of location dependent queries in mobile systems [2].

Currently, there are no Mobile Ad-Hoc Network (MANET) benchmarks. While conducting research in MANET data communication, it became apparent that a standard benchmark was needed to compare and evaluate competing MANET data communication protocols.

The proposed MANET data communication benchmark has three parts:

- **Standard Architecture:** The selected architecture mirrors the types of use a typical MANET will encounter.
- **Standard Workload:** The workload allows evaluation under identical conditions.
- **Evaluation Criteria:** The benchmark provides a common set of criteria to allow comparison.

In order to develop an appropriate benchmark for MANET data communication protocols two things are necessary. First, the architecture and uses of a typical MANET must be understood. Second, some discussion of current MANET data communication research is needed. These two items guide the development of the MANET data communication protocol benchmark's architecture, workload and evaluation, and are described in Sections 2 and 3, respectively. We then present the MANET data communication protocol in Section 4. In section 5, the proposed benchmark is used to evaluate TriM [5][6], a MANET data communication protocol. This evaluation is compared to simulation results. Conclusions are provided in Section 6.

II. MANET Architecture And Uses

In this section we present a basic MANET architecture and describe typical uses. A MANET is a collection of mobile servers and clients. All nodes (clients and servers) are wireless, mobile and battery powered [7]. The topology of a MANET changes frequently as nodes organize themselves automatically. A MANET has practical use whenever a temporary network is needed and no fixed infrastructure exists. The support of these applications can require a database to store and transmit critical mission information.

A MANET provides the traditional wireless network capabilities of data push and data pull, but also allows clients to communicate directly without the use of the server, unless necessary for routing [8]. Servers in a MANET have a larger share of resources [7]. Due to server's larger capacity they contain the complete DBMS and bear the responsibility for data broadcast and satisfying client queries.

Nodes (clients and servers) may not remain connected to the MANET throughout their life. To be connected to the network, a node must be within the area of influence of at least one other node on the network and have sufficient power to function.

In Fig. 1, a few nodes of a typical MANET are shown graphically. Each node has an area of influence. This is the area over which its transmissions can be heard. The area of influence will shrink as the battery power level decreases in a node.

Network nodes may operate in any of the three modes that are designed to facilitate the reduction in power used [9]. These are:

- **Transmit Mode**: This mode uses the most power, allowing transmission and reception of messages.
- **Receive Mode**: This mode allows the processing of data and reception of transmissions.
- **Stanby Mode**: In this mode, the CPU does no processing, transmitting or receiving.

Several scenarios exist in which a MANET would be a potential solution. Each scenario has specific needs that need to be addressed by a benchmark. They are described next.

A. Battlefield Scenario

In the battlefield scenario, vehicles and soldiers carry nodes. A vehicle can easily carry the larger and more powerful server. Soldiers, carrying the lighter clients, will at times be transported by vehicles and at times will be on foot. Vehicles and soldiers have different rates of travel, but typically move in the same direction. The geographic area covered in this scenario can be quite large and networks may be sparsely populated.

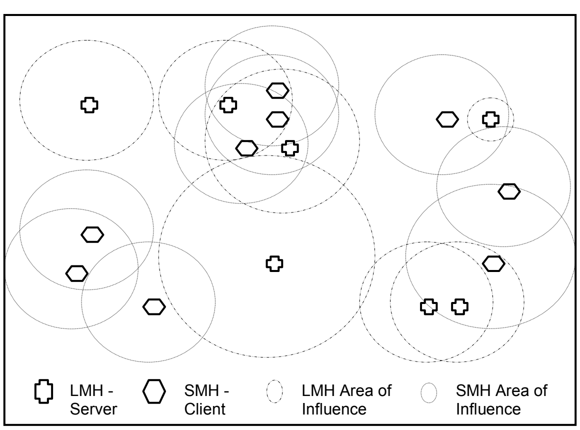

Fig. 1. Typical MANET Architecture

The MANET can best be deployed at the brigade level where all nodes are mobile [10]. A brigade has as many as 1000 SMHs with 15 to 20 LMHs covering an area roughly 10 by 15 kilometers [10].

B. Domestic Rescue Scenario

In a rescue situation, vehicle movement is often slow and restricted. Most vehicular travel follows existing roads which are generally regular and grid-like [11]. Travel may also be on foot, leading to regular but slow topology changes. While the direction of travel may be unpredictable, the region of travel is not. Movement is confined to a set geographic region.

We also consider the size of a rescue team. A Federal Emergency Management Agency Incident Response Team is made up of 40 individuals, providing 24 hour support [12]. The teams involved in a rescue range from small teams of 3 to 5 up to large teams of 50 to 60. The rescues are usually building collapses due to earthquakes and terrorist activity. In this scenario, the number of clients served by each server is not large.

C. Business Scenario

In a MANET for a trade-show or similar business situation there will be little or no vehicular traffic. Rather individuals on foot will carry nodes. The area of interest will be easily defined and battery-powered servers can be placed to provide full coverage. Within this environment, there are potentially hundreds of clients. Johannsson [13] refers to this as the event coverage scenario. They modeled 50 highly mobile users. In this scenario typical mobility will be walking in the 0 to 1 m/s range [13].

III. Current MANET Data Communication Research

In the current literature for MANET data communication, a wide variety of architectures, workloads and evaluation criteria are used. Table I shows common values in the studies referenced. These studies were selected as all involve MANET data communication and they are representative of research in this area. These studies also provide a sample of expected values for benchmark parameters.

We should note that the list of parameters provided do not address all architecture parameters necessary. In addition to these parameters, we need to know node bandwidth, CPU performance and power dissipation rates. These are important when considering the effects of data communication in a MANET. Only [7] provided these parameters.

TABLE I
COMMON MANET ARCHITECTURE PARAMETERS

	#nodes	mobility (m/sec)	Region Size (m)	Simulation Time (sec)
Gruenwald [7]	3-5 Server 1000 Client	n/a	500 x 500	n/a
Jung [11]	256	n/a	200 x 200	n/a
Kunz [14]	50	1 - 20	1K x 1K	900
Tang [15]	75 – 300	n/a	500 x 500	120
Tseng [16]	100	0 – 30	500 x 500 to 5500 x 5500	n/a
Wieselthier [17]	50	n/a	5 x 5 Grid	1000 work units
Williams [18]	20 – 110	n/a	350 x 350	100
	60	n/a	350 x 350	100
	60	1 - 20	350 x 350	100

The typical workload parameters used in five of these referenced studies are shown in Table II. Workload refers to the database and communication needs of the network. Tang's and Wieselthier's works are not included, as they provided no values for these parameters. The three lines in Table II for the Williams entry correspond to the three different sets of values shown for Williams in Table I.

In addition to these parameters a MANET data communication benchmark needs data broadcast and peer-to-peer parameters.

The evaluation criteria among these research projects are quite varied. For example, Wieselthier used *Broadcast Effectiveness* [17]. This measures the average number of data packets received to the number of data packets sent. Gruenwald uses *Hit Ratio*, measuring how well a broadcast satisfies the data needs of a client [7]. Williams chose to evaluate his protocol by measuring packet delay in the delivery of requested data items [18]. Tang suggests evaluating a MANET protocol based on the power consumed [15]. Wieselthier is indirectly concerned with power. He measures the amount of work accomplished for each unit of power used [17].

Certainly these are all important measurements. However, their variance makes protocol comparison difficult. Rather than trying to mix and match a variety of criteria, the benchmark will propose criteria that together measure overall and communication mode specific performance while giving a reasonable picture of the overall MANET data communication protocol performance.

IV. PROPOSED MANET DATA COMMUNICATION BENCHMARK

In the following sub-sections we discuss each of the benchmark's three parts: architecture, workload, and evaluation criteria.

A. Benchmark Architecture

The proposed architecture for the MANET data communication benchmark has two parts. The first part consists of the common elements found in every MANET. The second part is scenario specific. A single benchmark architecture cannot encompass all potential MANET scenarios. There are three scenarios presented. The selected common parameters are shown in Table III while scenario specific values are in Table IV.

The general and scenario specific parameters of MANET architecture were chosen after considering current research in MANET data communication and scenario specific characteristics as presented in Sections 2 and 3. Where there is no general agreement on the value, a value is selected based on our own judgment. The CPU processing power and power dissipation rates

TABLE II
COMMON MANET WORKLOAD PARAMETERS

	Packet Frequency (pkt/sec)	Packet Size (byte)	Broadcast Radius (m or unit)
Gruenwald [7]	n/a	25K	Server – 200 Client – 100
Jung [11]	n/a	120	n/a
Kunz [14]	4	512	250
Tseng [16]	n/a	280	500
Williams [18]	10 1 – 80 10	64	100

TABLE III
BENCHMARK ARCHITECTURE PARAMETERS

Parameter	Value
Bandwidth Server / Client	2 Mbps / 100 Kbps
Communication Radius Server / Client	250 meters / 100 meters
CPU Power Server / Client	1700 MIPS / 100 MIPS
Power Dissipation Rate (Active/Doze/Sleep) Server Client	170 / 20 / 2 watts 7 / 1 / 0.1 watts
Simulation Time	1 hour (3600 sec)

TABLE IV
SCENARIO SPECIFIC BENCHMARK ARCHITECTURE PARAMETERS

Parameter	Battlefield	Rescue	Business
# Nodes Client Server	 20 1000	 1 - 10 10 - 50	 4 - 6 1000
Mobility (m/sec)	0 to 20	0 to 10	0 to 1
Region Size (km)	10 x 15	5 x 5	1 x 1

are set for a server using a Intel Pentium IV 1.5 GHz CPU and a client using a Pentium III 450 MHz CPU.

Some values in Tables III and IV are used in the evaluation portion of the benchmark. Some benchmark parameters describe the behavior of nodes in the network, allowing protocol specific values to be set. For example, mobility is the speed traveled by nodes and region size is the area in which a MANET is operating.

B. Benchmark Workload

No single packet or message frequency, database size or broadcast size is selected in the data communication protocol. Instead a set of values is provided. This allows the testing of a wide range of potential situations.

Request frequency is the frequency of client data requests during data pull. Message frequency is the frequency of messages when performing peer-to-peer communication. It is assumed that all nodes have the same request and message frequencies. The value used in data broadcast is the broadcast size. These values are shown in Table V. Full replication of the database among all servers is assumed.

TABLE V
BENCHMARK WORKLOAD PARAMETERS

Parameter	Value
Database Size	500 / 2000 / 5000 items
Broadcast Size	50 / 100 / 200 items
Frequency of Data Request	5 / 20 / 40 requests/sec
Frequency of Messages	5 / 20 / 40 messages/sec
Index Item Size	128 bytes
Data Item Size	64 Kbytes
Data Query Size	256 bytes
Message Size	512 bytes

C. Benchmark Evaluation

The evaluation of MANET data communication is a complex matter. Two items require measurement. First, the ability to provide all modes of data communication must be measured. If the protocol cannot perform those functions, other evaluation is unimportant. We do this by measuring overall data communication performance as well as the performance of each data communication type.

In addition, the MANET specific characteristics must also be evaluated. These characteristics are mobility and battery power. If nodes cannot find and communicate with each other or nodes run prematurely short on power, no protocol will make the MANET usable.

In the evaluation portion of this benchmark we have three types of values. We have benchmark values, defined in the architecture and workload. Second, we have evaluation values that are the results of measuring system performance. Finally, we have protocol specific values. These are values that vary by protocol. These values are described here, but the values are protocol dependent.

In this benchmark, we group together a set of evaluation criteria that measure the basic performance of MANET data communication protocols. The purpose of this benchmark is to codify a benchmark to allow efficient comparison and evaluation of MANET data communication protocols.

When measuring overall system performance, the effect of data communication on power consumption and the effect of mobility on data communication are important concerns. This MANET data communication benchmark measures both.

The evaluation criteria proposed are:

- Average server power consumed.
- Average client power consumed.
- Percent of broadcast coverage.
- Broadcast effectiveness
- Query efficiency
- Peer efficiency.

For power consumption, the average power consumed by clients and servers is maintained independently at each node as total power consumed. From this we can calculate average power consumed per unit time.

Percent of broadcast coverage measures the percentage of client's able to hear the data broadcast of the nearest server. This criterion indirectly measures the percentage of client's not currently connected to the network. If a client cannot hear data broadcasts it will be hampered.

Next we address measurements for specific data communication methods. These methods are data broadcast, data query and peer-to-peer communication.

The measure to monitor data broadcast will be broadcast effectiveness. This criterion measures the percentage of items heard by each client via data broadcast that are of interest to that client. Broadcast effectiveness has two parts. First the broadcast efficiency is measured for each broadcast transmission. Second the average for all broadcasts during the entire life of a MANET is deployed is calculated.

The broadcast effectiveness is kept sufficiently general that it works when all broadcasts are of the same or differing lengths.

For data query, we measure the percentage of data requests satisfied. This is referred to as query efficiency. This is an average for all clients over the life of the network. Each node tracks the number of data queries made and serviced.

For peer-to-peer communication, we measure the percentage of peer messages delivered. This criterion is peer efficiency. This is averaged for all clients over the life of the network. Peer efficiency is measured by comparing the number of messages sent to peers by the number of messages received by peers. This is a system wide measurement. Each node tracks the number of messages sent and received.

These criteria details the evaluation criteria used by the MANET data communication benchmark to compare different data communication protocols.

V. Analysis And Simulation

TriM, a MANET data communication protocol is described in [5][6]. It will not be presented here. The importance here is to compare the values obtained through evaluation to those obtained through simulation. In this section, the benchmark evaluation criteria were calculated for the business scenario described earlier. Full details on these calculations can be obtained from [5].

Before calculating the benchmark parameters for our scenario some additional information is needed. We assume that the maximum number of servers and clients specified in Table IV. We also assume no overlap of servers to calculate the maximum area of coverage. To calculate the maximum area of coverage, we calculate the area reached by a single server transmission and multiply by the number of servers. We then divide this number by the size of the roaming region, giving the maximum percentage of area covered by a server's broadcast transmission.

The first benchmark evaluation criteria we consider are average power consumption for servers and clients. We simplify the calculation of the equation for predicting performance of the protocol by calculating the average time spent in transmit, receive and standby for all clients and servers during the life of a MANET running TriM. We calculate the average value for all clients and servers.

Network connectivity is measured as the percentage of clients that are in range of a server data broadcast transmission. This calculates the average number of clients hearing a broadcast to the number of clients in a network over the life of the network. It is assumed that nodes are initialized in random locations, within a defined region and move randomly.

Assuming random distribution of the clients and servers, the expected broadcast effectiveness should be similar from one broadcast to the next. The majority of clients should be served by data broadcast in the business scenario.

The second method of data communication is data query. We indirectly measure the effectiveness of data query when we measure the connectedness of the network. We more directly measure the effectiveness of data query by calculating the percentage of data queries that are served over the life of the network.

When evaluating the expected performance of TriM on query efficiency, we use the probability that a client is within transmission range of a server to estimate the number of queries served. If a query can be immediately processed, and there is time to transmit a response, we assume the query is served. When considering the effect of network disconnection on the percentage of data requests satisfied, it is clear that disconnection can have a significant effect.

Peer efficiency will be affected by disconnection from the network in a similar fashion to query efficiency. Here, any queries that must be routed require the presence of a server. Queries sent directly only rely on the presence of the recipient client.

In Table VI, the calculated and simulated values are compared. In each case, the simulated values are within the range of the calculated values. The calculated values represent calculations for different probabilities of clients and servers being detected and available (0.5 to 1.0). In the business scenario, the number of clients and the number of servers is large and the size of the network region is comparatively small. For this reason, it is expected that the probability of each client and server being detected and available within the network is high

The simulated results show that while the clients and servers were detected and available in most cases, they were not available 100% of the time. The range in power consumption values are for the range of workloads shown in Table V.

TABLE VI
BUSINESS SCENARIO CALCULATED BENCHMARK CRITERION COMPARED TO SIMULATED VALUES

Criterion	Calculated	Simulated
Average Server Power Consumption (watts)	100 – 170	81 – 163
Average Server Power Consumption (watts)	0.5 – 1.5	0.5 – 1.01
Broadcast Coverage (%)	100	66
Broadcast Effectiveness (%)	40 – 80	65
Query Efficiency (%)	15 – 20	17
Peer Efficiency (%)	50 – 80	57

VI. CONCLUSIONS

In this paper we develop and propose a benchmark for the evaluation of MANET data communication protocols. The benchmark was then used to evaluate Trim [5][6], a MANET data communication protocol, in a business scenario. These results are then compared to simulation results for the same scenario. Future efforts will center on refining the benchmark in collaborative efforts with others working in this area and the inclusion of new scenarios as the potential uses for MANET increase.

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