# TriM: Tri-Modal Data Communication in Mobile Ad-Hoc Networks

Leslie D. Fife[1], Le Gruenwald[2]

[1] Computer Science Department, Brigham Young University – Hawaii, Laie, HI 96762
ldfife@cs.byuh.edu
[2] School of Computer Science, University of Oklahoma, Norman, OK 73019
ggruenwald@ou.edu

**Abstract.** A MANET is a group of wireless, mobile, battery-powered clients and servers that autonomously form temporary networks. Increasingly, research in MANET data communication has been addressed. Three data communication modes can be provided in a MANET, data broadcast, data query, and peer-to-peer messaging. Currently, no MANET data communication protocol provides the ability to use all MANET data communication modes. The objective of this research is to develop a MANET data communication protocol, TriM (for Tri-Modal communication), capable of providing all three data communication methods. TriM was designed to accommodate network disconnection and reconnection through periodic synchronization. Protocol design provides contention free data broadcast. Each part of the protocol design has minimum power consumption as a goal. Simulation showed TriM minimizes the average power consumption of servers and clients while accommodating node disconnection. Simulation also showed that TriM performs well in comparison to the Leader Selection protocol.

## 1 Introduction

A MANET is a collection of mobile servers and clients. All nodes (clients and servers) are wireless, mobile and battery powered [4]. The topology of a MANET changes frequently as nodes organize themselves automatically. A MANET is a potential solution whenever a temporary network is needed and no fixed infrastructure exists. MANETs differ from traditional mobile networks. In a traditional mobile networks, there are mobile, battery-powered clients. There may also be fixed clients that are on the power grid. The servers are stationary and powered by the fixed power grid. The servers communicate with the mobile clients over a wireless link. Fixed clients may receive data over a wired or wireless link. A traditional mobile network communicates only through data push (data broadcast) and data pull (data query) while a MANET provides the traditional wireless network capabilities of data push and data pull as well as allowing clients to communicate directly in peer-to-peer communication without the use of a server, unless necessary for routing [1]. Due to servers having a larger capacity than clients [4], in this research we assume that servers contain the complete database management system (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. The area of influence is the area over which a node's transmission can be heard. In Figure 1, a few nodes of the MANET architecture used in this research are shown graphically. Some research assumes a variable powered broadcast transmission. For example, Wieselthier sets the transmission level as part of the algorithm for building the broadcast tree [15]. In this research, we assume a fixed transmission power level. Because of this, the area a broadcast transmission reaches is determined primarily by the amount of power remaining in the node's battery. As the power level decreases, the area of influence of any node will shrink.

Network nodes (clients and servers) may operate in any of the three modes that are designed to facilitate the reduction in power used [7]. 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.
- **Standby Mode**: In this mode, the CPU does no processing, transmitting or receiving.

Traditional mobile network research must address the mobility of clients, the battery-power of clients and the limitations of the wireless bandwidth. MANET must consider these issues as well as the battery power and mobility of the servers. These additional restrictions prevent the use of current traditional mobile network routing and data communication protocols, which assume unlimited power and a fixed topology for all data servers.

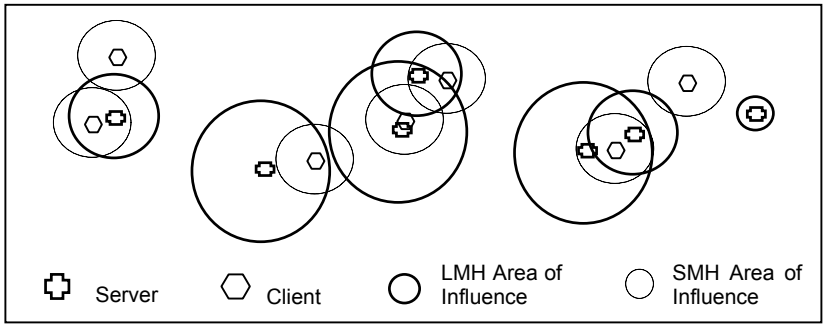


**Fig. 1.** Typical MANET Architecture

Originally, the majority of research in MANET has centered on routing issues [1][6]. Over the past few years, interest in data communication has been increasing [4][16][17]. However, current MANET data communications protocols have provided only one or two modes of data communication. No current protocol provides the ability for a MANET to use all three modes of data communication. This paper presents a MANET data communication protocol that allows all three modes of MANET data communication.

The rest of this paper is organized as follows. Section 2 will present the current research in MANET data communication. In Section 3 TriM, a MANET data communication protocol allowing all three modes of data communication is proposed. Section 4 describes the scenarios simulated and the results of the simulations for the TriM protocol. Section 5 provides conclusions and outlines future work.

## 2 Current MANET Data Communication Research

Most current MANET data communication protocols provide data push while some provide only data pull or peer-to-peer communication. Data push is used, as it is energy-efficient. A broadcast heard by one client requires no more server power than a broadcast heard by hundreds. A MANET using data push and data pull must consider the data communication issues associated with a traditional mobile network. These issues include broadcast size and organization, selection of items for broadcast, and network bandwidth [10]. MANET must also consider the power consumption and mobility of the server(s) as well as clients [10].

The data communication research issues in MANET databases center around two areas. These issues are covered in detail in [3]. The first area concerns the limitations of the environment (wireless, limited bandwidth, battery powered, mobile). The environmental issues are power consumption for both clients and servers, handling of mobility and disconnection, access and tuning time minimization and data integrity. The second area concerns the three ways in which MANET data communication may take place. Within this area, concerns due to data push (broadcast), data pull (query) and peer-to-peer communication (peer messaging) exist. Data broadcast issues include the content and frequency of data broadcasts, the allocation of broadcasts among servers and the reasonableness of a server transmitting a broadcast. Data pull issues center on who serves a data request and what happens to a data request that is not served promptly. Peer messaging issues include routing of messages and how un-served peer messages affect the protocol.

Some work in MANET data communication has been scenario specific. In the work of Jung, et al [8], broadcast in urban areas is addressed. Specifically, Jung deals with the issue of Location Dependent Queries (LDQ). Tang, et al [13] adapt MANET data broadcasting to the more specialized power controlled wireless ad-hoc networks. In these networks, servers have the ability to broadcast at one of several discrete power levels. This allows the server to choose a power level appropriate for reaching the maximum number of clients while avoiding interference with other servers

[13]. The work of Kunz and Cheng [9] demonstrated that tree-based routing algorithms for on-demand data service are not efficient. They suggest that a mesh-based routing algorithm, where there are multiple paths between nodes, is more efficient and resilient in a mobile environment. The work of Tseng, et al [14] deals with a specific problem with wireless broadcast. This is the broadcast storm. They demonstrate through simulation that overlapping broadcast regions can create a significant problem in MANETs [14].

Wieselthier, et al have been working on MANET data broadcast. Their approach is the construction of a minimum-energy tree rooted at the broadcast source [15][16]. Two algorithms called Broadcast Incremental Power (BIP) and Multicast Incremental Power (MIP) have been advanced for building these trees. The BIP builds the minimum energy tree for a broadcast, while the MIP uses the BIP algorithm, but only includes those branches necessary to reach the clients needing to receive a specific broadcast [15]. The algorithms were tested and showed that by utilizing broadcast in a mobile environment, energy savings can be achieved. Further studies with larger networks were recommended [15]. However, node mobility was not addressed.

The cost of building the tree is considered negligible by the authors as the use of the tree is long when compared to the building of the tree [15]. This would be the case for stationary nodes. However, stationary nodes are the exception in MANET. Wieselthier accommodates "movement" with the observation that increasing transmitter power will allow them to reach nodes in new locations [16]. No potential interference between broadcasts and no need to rebuild the tree once created are considered. In addition, it has been shown that tree-based protocols do poorly when there is node mobility [5]. The problems of limited bandwidth, the need for tree maintenance, and node mobility remain.

Two algorithms to handle data push and data pull within the MANET were proposed by Gruenwald, et al. [4]. The first is the adaptive broadcast scheduling algorithm. Within this algorithm there are two potential ways to construct a broadcast. New items may be either added to the algorithm or may replace less important data items [4]. A global network where all servers in a region know the location and power of all other servers in the region and full replication of the database is assumed. Periodically, each server broadcasts its location and power level. This begins the broadcast cycle [4]. Data deadlines are used to determine which data requests to service although no penalty for missing a deadline is specified. This protocol includes a leader selection protocol that elects the server in a region with the greatest remaining power. The leader coordinates the broadcast responsibilities of other servers in its area of influence [4]. The lead server determines which portion of a broadcast each server transmits. The power level of each server drives this broadcast assignment. The server with the least power transmitted the most important data items [4]. No server transmits the entire broadcast unless it is the only server in a region. After the conclusion of broadcast transmission, clients are permitted to query the servers for a time then the broadcast cycle repeats [4]. This initial algorithm has a potentially large overhead as mobility may cause the leader selection protocol to run frequently. While selecting a leader, less popular items may starve or be broadcast too late [4]. In addition, servers with no clients still broadcast, wasting power.

The second algorithm utilizes a popularity factor (PF), as suggested by Datta, et al [2]. The PF is a measure of the importance of a data item. The PF increases each time a request is made for a data item [4]. The amount of time since the request was made also affects the PF. If it has been too long, the need to broadcast the item may be gone. This factor is called the Resident Latency (RL) and is system and scenario specific [4]. The PF decreases whenever a request exceeds the RL value [4]. The PF is used to assist in the building of relevant broadcasts and includes RL in order to make allowances for the movement of nodes. When the PF of broadcast items is high, the probability of a broadcast that serves maximum needs increases. If a server has not received any requests for a certain number of broadcasts, it will sleep rather than broadcast to an empty audience [4]. Finally, to localize data delivery, the lead server assigns each server the amount of data to broadcast but not the items to broadcast [4]. This approach is still not sufficient as servers can be assigned a broadcast larger than their power levels would permit. In addition, adding the popularity factor and the calculation of resident latency only add to the overhead, further delaying data delivery.

## 3 TriM Data Communication Protocol

In the following sections, the TriM data communication protocol is presented, by stage. The specific parameters used to control the protocol are not listed due to space limitations but are available in [3a]. This paper serves to describe the overall design of the protocol. In Figure 2 we see an overview of the proposed protocol. This figure shows a single iteration. The protocol will cycle through these stages repeatedly. A single time through the protocol is referred to as a service cycle (SC). Here we clearly see the relationship of each data communication mode within the various protocol

stages. Prior to the first iteration of the service cycle, the network is initialized and deployed. At this time, all protocol parameters are set. Currently, these parameters are static for the life of the network.

In two of the four stages shown, data communication can take place. These are the data push stage and the data pull stage. The synchronization stage allows LMHs/SMHs to synchronize and detect the other nodes in their immediate vicinity. The idle stage allows the setting of a period of time during which all nodes are inactive. This gives the network designer the ability to set the frequency of data communication within the network. By setting this parameter carefully, we can avoid too frequent repetition of broadcasts or the other energy expensive portions of data communication. The service cycle repeats until the network is taken out of service or all nodes fail.

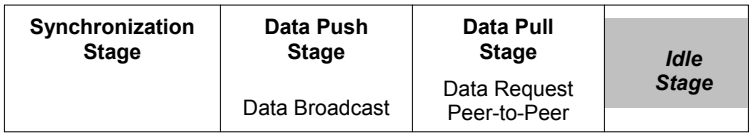


**Fig. 2.** TriM Data Communication Protocol

### 3.1 Network Initialization and Control

There are four stages, synchronization, data push, data pull and idle, in the TriM data communication protocol. The first three are active while the last one is inactive. Within each stage there are tasks associated with the servers and tasks associated with the clients. These are discussed separately for each stage.

Network initialization is accomplished when deploying a MANET. The network designer determines the length of each of the network stages according to the needs of the network and the expected characteristics of that particular deployment. Network initialization involves a variety of parameters. Each node in the network (server and client) is initialized using the same parameter values. These values remain the same throughout the MANET deployment, allowing synchronization during the lifetime of the network. The database maintained by the servers is assumed to be fully replicated. Each server and client independently monitors its location in the Service Cycle based on these common parameters and uses them for any necessary synchronization with other nodes.

### 3.2 TriM Synchronization Stage

The synchronization stage has two parts. The first part is restricted to the transmission of information by servers (LMHs). Servers transmit their unique ID and location. This information is necessary to perform message routing during peer-to-peer communication and is used by SMHs during data query to select the nearest LMH to query. There are generally fewer LMHs and their individual presence is critical to the protocol. Sufficient time is allocated during LMH synchronization to allow all LMHs to transmit their information in order. Each LMH knows the number of LMHs that were deployed during network initialization. The unique IDs are numbered from 1 to $n$. Each LMH transmits its information in turn, waiting the appropriate period of time before transmitting its information. The importance of the LMH information to the protocol prohibits transmission in parallel. Collisions in the limited bandwidth of wireless networks could cause the loss of information and the failure of neighboring LMHs from knowing about one another. The amount of time a LMH must wait is determined by the number of LMHs having smaller IDs and the time needed for it to transmit its location.

The second stage is for transmission of information by clients (SMHs). Each SMH transmits their unique ID and location. To perform routing of peer-to-peer messages during the data pull stage, the location of each SMH is needed. However, the number of SMHs is potentially large and it may not be possible to reserve sufficient time for each SMH to transmit independently. SMHs transmit their information when the transmission channel is clear. SMH's location information is updated when synchronization provides new information. Otherwise the protocol uses old, potentially inaccurate information to make routing decisions.

The synchronization stage is also important as it synchronizes all nodes in the MANET. By regularly synchronizing all nodes, each node will be in the same protocol stage at the same time. This prevents contention over the limited network bandwidth. This is especially important during data broadcast, which immediately follows synchronization. Synchronization prevents LMHs from transmitting at the same time, wasting power and the limited network

bandwidth. The results of synchronization also play a role in data query and peer-to-peer communication. The synchronization stage occurs once per service cycle. During synchronization, nodes can determine if they are currently disconnected from the network. If a node detects no other nodes during synchronization, it will sleep until the next service cycle.

### 3.3 TriM Data Push Stage

The second stage of the service cycle is the data push or broadcast stage. The data push stage occurs before data pull so that the maximum number of potential data needs can be served before a server becomes too weak to transmit data. Separating data push and data pull reduces the contention for the limited bandwidth. When the data needs of a client are satisfied by the broadcast, the need for data query is eliminated. This results in a power savings.

**3.3.1 Servers – Data Push Stage** The autonomous and mobile nature of this self-organizing network suggests independent LMHs. This eliminates the need for and energy consumption of a leader selection protocol. The decision of whether to transmit a data broadcast is a local one, made by each server. The contents of the broadcast are also partially determined by each server. The data broadcast will be composed of both a pre-selected set of data items and a set of dynamically selected items. The pre-selected items are determined at MANET deployment by the network designer. These are data items that each client needs frequently. The fixed portion of the broadcast is the same for each LMH. The dynamic portion of the data broadcast will vary, depending on the unserved data queries of the SMHs within transmission range of each LMH during the previous service cycle.

Figure 3 shows the broadcast portion of the service cycle for servers. Two possible situations are shown. In the first situation, the server has insufficient power to transmit an index and data broadcast. The LMH will go into standby mode. In the other case, the index and broadcast are transmitted in server ID order with each server being allocated a broadcast slot to prevent collision. As the size of the MANET broadcast is meant to be of minimal size, a single transmission of the index is preferred as transmission of the index takes time and consumes power. Servers do not listen to the broadcast transmissions of other servers. As several servers may broadcast in the same region, duplication of the broadcast static portion is a waste of power. To some extent, this cannot be prevented. A client may be in the transmission range of several or only one of the servers, depending on its geographic location.

**3.3.2 Clients – Data Push Stage** Clients, like servers, have two potential situations during data push. If a client detects no servers during synchronization, it will be in standby. The client behavior is shown in Figure 4. Each SMH knows from the synchronization stage which LMHs will transmit in their region. The SMHs can then tune into receivable transmissions. The SMH will receive the static portion from any of the LMH transmissions it receives, but need only listen to the static portion once. A SMH will also check the index for any needed dynamic data items. It will use the index to determine when the data item will be transmitted. The index contains a list of all data items that will be transmitted as a part of the broadcast, and the order in which they will be transmitted. A SMH needs only listen to transmitted indices, the static data portion once and dynamic data items of interest. To listen to these items, the SMH must be in receive mode. The remainder of the time, the SMH may be in sleep mode.

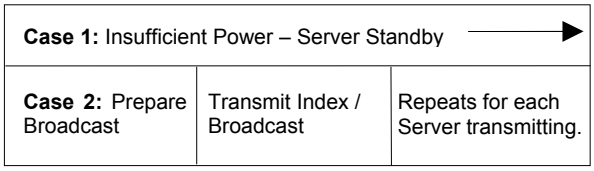


**Fig. 3.** TriM Data Push Stage – Server

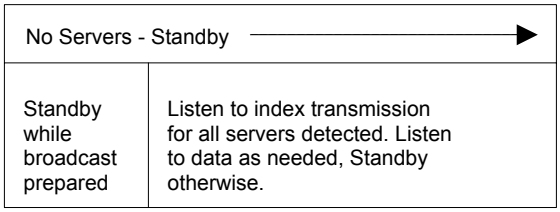


**Fig. 4.** TriM Data Push Stage - Client

### 3.4 TriM Data Pull Stage

During the data pull stage, both data query and peer-to-peer communication occur. During data query, servers respond to data requests from clients. A server may also be asked to do routing of peer-to-peer communications. In data query, clients request data from servers when the data they need was not in the recent broadcast. In peer-to-peer communication, clients communicate directly with other clients. If the client contacted is disconnected from the network, the message is dropped. During data pull, all nodes are aware that their transmission may not be heard as nodes detected during synchronization may now be out of transmission range. For this reason, clients will not retransmit the same query or peer message twice during the data pull stage in a single service cycle.

**3.4.1 Servers – Data Pull Stage** The actions of servers during the data pull stage of the service cycle is shown in Figure 5. The servers have two primary tasks during the data pull stage. First they must respond to data queries. Any data query that is not serviced during this data pull stage is added to the dynamic data portion of the broadcast in the next service cycle. Second, servers must route client peer communications when requested.

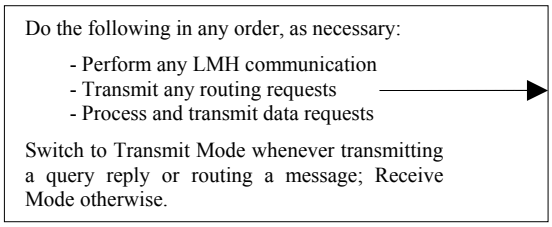


**Fig. 5.** Trim Data Pull Stage - Server

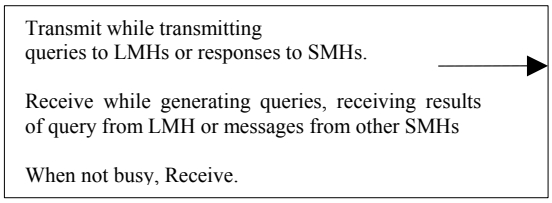


**Fig. 6.** TriM Data Pull Stage – Client

**3.4.2 Clients – Data Push Stage** A SMH has only a few potential tasks during data pull as shown in Figure 6. The first situation is when a client needs to make a data request. The client will be in transmit mode while transmitting the data query and will be in receive mode as it awaits a response. Second, a client may need to communicate directly with another client. If the target client is detected during the most recent synchronization stage, it will transmit to the target directly. Otherwise, a routing request will be sent to a server. Finally, a client may receive a peer message. If this occurs, the receiving client will create a reply, change to transmit mode and transmit the reply.

### 3.5 TriM Idle Stage

Following the data pull stage a MANET will enter into a period where all nodes are in standby. The length of this period is determined by the network designer and is set at network deployment. Standby spreads out data push and data pull stages and uses very little battery power. This period is determined by the necessary frequency of broadcasts for the network to perform its designed functions. Following the idle stage, the service cycle will repeat.

## 4 Simulation of TriM

In order to test the TriM protocol, a variety of scenarios were simulated. The AweSim simulation software [12] using inserts coded in the C programming language to describe network behavior was used for this simulation study. AweSim is a general-purpose simulation tool that provides discrete event simulation of user defined networks [11]. The deployment of a MANET and the execution of the proposed MANET data communication protocol can be defined as a set of discrete events that occur during the operation of the protocol. These events are network deployment and initialization, repeated execution of the MANET data communication service cycle (SC), and a network report event that executes once at the conclusion of network simulation. In order to compare TriM to the Leader Selection protocol [4] simulations are performed with values matching those used in that study. Additional scenarios were run using as a guideline the parameters used in [8][9][13][14].

The simulation runs vary data push parameters and data pull parameters. Three data broadcast sizes (50, 100 and 200 items) are simulated for each of the data pull settings. These broadcast sizes are referred to in the results as small, medium and large broadcasts, respectively. The data pull parameters are the frequency of data query and peer messaging. Data query and peer messaging are set to the same value. As both data query and peer message frequency are set to the same value, they are referred to collectively as pull frequency throughout this paper. The values used for pull frequency are 5, 20 and 40 items/sec. These are referred to as low, medium and high pull frequency, respectively. This variation simulates different loads on the network. This results in nine different workloads for each of the three scenarios. Each of the nine workloads was simulated 10 times. Table 1 shows other parameters used in the simulation. The simulations assume that the LMHs and SMHs are initialized in random locations throughout the roaming region. Once the network is initialized, motion of all nodes is random with respect to speed and direction. However, the random speed must be within the mobility range and roaming region specified.

**Table 1.** Parameters for MANET Data Communication Simulation

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Bandwidth<br>LMH<br>SMH | <br>2 Mbps<br>100 Kbps | LMH Power Dissipation Rate<br>Transmit Mode<br>Receive Mode<br>Standby Mode | <br>170 w<br>20 w<br>2 w |
| Communication Radius<br>LMH<br>SMH | <br>250 meters<br>100 meters | SMH Power Dissipation Rate<br>Transmit Mode<br>Receive Mode<br>Standby Mode | <br>7 w<br>1 w<br>0.1 w |
| CPU Power<br>LMH<br>SMH | <br>1700 MIPS<br>100 MIPS | Mobility – all nodes | 0 to 1 m/sec |
| Number of Nodes<br>LMH<br>SMH | <br>6<br>1000 | Size of roaming region | 1 km x 1 km |
| | | Simulation Time | 1 hour |

As with any simulation, some assumptions must be made. During the SMH portion of synchronization, the average number of SMHs within reach of each LMH must be calculated. As the nodes are distributed randomly in the region, the average used is *number of SMH / number of LMH*. The next stage is the data push stage. In this stage, a broadcast is built. It is assumed that each broadcast transmission is equally split between static and dynamic data items. This means that a broadcast is always at least half full. It is further assumed that a SMH listens to the static portion of one broadcast transmission and to the entire dynamic portion of each broadcast transmission in its region. In data pull we assume a static number of data queries and peer messages per node. The values used in the simulation are request frequencies of 5, 20 and 40 queries/messages per second. During simulation, the distance between nodes is calculated and compared to benchmark transmission ranges to determine if a SMH can hear a LMH and if a SMH transmission can reach other nodes. It is assumed that a SMH will send all data queries and routing requests to the closest LMH detected during synchronization if it is within SMH transmission range.

### 4.1 Evaluation Criteria

We study the performance of our protocol using the following evaluation criteria

- **Average Power Consumption** The average power consumed by clients and the average power consumed by servers are calculated. For each client and server the power consumed per time unit is calculated by multiplying the percentage of time a node spends in each mode by the cost in power dissipation of each power mode.
- **Percentage of Coverage** The effect of mobility that we measure is the percentage of SMHs out of range of all data broadcasts transmissions. This demonstrates the effect of network mobility and implies the level of node disconnection in the network.

- **Broadcast Effectiveness** The broadcast portion of the MANET is important, as data push is energy efficient. The measure for this portion of data communication will be broadcast effectiveness, which is the ratio of items of interest in a broadcast to the total number of items transmitted.
- **Query Efficiency** The data pull section will rely on the measurement of query efficiency. This is a measure of the percentage of data queries that get served during an entire simulation.
- **Peer Efficiency** Peer-to-peer communication is a time when clients can communicate directly with clients. Peer efficiency is measured as a percentage of the messages sent to peers by the number of messages received by peers.

### 4.2 Simulation Results

The initial scenario simulated was a comparison between the Leader Selection protocol [4] and TriM. The Leader Selection protocol is a soft real-time MANET data broadcast protocol. Data query, as described in this paper does not exist. Rather, data requests help inform the building of subsequent data broadcasts. Individual data items are not served interactively and no peer-to-peer communication occurs. This protocol is selected for comparison to TriM as it is one of the few MANET data communication algorithms that allow multiple data communication methods while providing sufficient data for comparison. This protocol provides 4 measures for evaluation, which are energy consumed by LMHs, energy consumed by SMHs, access time and broadcast hit ratio. A complete comparison cannot be made due to protocol differences. However a partial comparison is possible. Energy consumption is measured for both LMHs and SMHs in both protocols. In addition, our Broadcast Effectiveness (BE) is similar to the Broadcast Hit Ratio (BHR) of [4] when the probability that dynamic items in the broadcast are of interest is 1. To make the comparison as accurate as possible, the simulation used as many of the parameters of [4] as possible, including number of SMHs and LMHs, CPU power, bandwidth, and transmission radius, size of simulation region and database size. Each LMH transmitted 20% of the database in each data broadcast. Table 2 shows the comparison between Leader Selection and TriM. Peer Efficiency and Query Efficiency were not calculated, as they have no corresponding value in [4].

The behavior of TriM was similar to the Leader Selection protocol. The major departure is in the SMH power consumption. This is due to a difference in how SMHs are used in the two protocols. In Leader Selection, SMHs drive the contents of the data broadcast. In TriM, the SMHs only request what was not received in a recent data broadcast. The primary advantage of TriM over Leader Selection is the addition of peer messaging and interactive data query, which are not available in Leader Selection. TriM compares favorably with Leader Selection.

**Table 2.** TriM Comparison to Leader Selection Protocol

| | TriM | Leader Selection | | | TriM | Leader Selection |
|---|---|---|---|---|---|---|
| SMH Avg Power Consumption (watts) | 0.19 | 20-60 | | Percent SMH Hearing Broadcast | 95.9 | Not applicable |
| LMH Avg Power Consumption (watts) | 18.99 | 15-24 | | Broadcast Effectiveness (Broadcast Hit Ratio) | 70.36 BE | 60-100 BHR |

The remainder of the data presented is for the 9 workloads described above. It should be noted that when a LMH must choose between routing peer messages and serving data queries, routing takes precedence. The rationale is that data queries can be added to the next data broadcast while peer messages are dropped at the end of data pull. Figure 7 shows the average client power consumption simulation results for all 9 variations of broadcast size and pull frequency. Figures 8, 9, 10, 11 and 12 show the average LMH power consumption and the percentage of SMHs hearing a broadcast, Broadcast Effectiveness, Query Effectiveness and Peer Effectiveness, respectively.

To understand the results, it is important to know that the length of each stage of the service cycle changes from one workload to the next. For instance, as the maximum size of the data broadcast increases, so does the length of the data push stage. When the pull frequency increases, the data push stage is also increased in length. As the length of the service cycle increases because of a larger data broadcast, the average power consumption for LMH decreases as less time is spent transmitting. While each broadcast transmission is longer, the amount of time waiting for the other LMHs to transmit also increases. As the length of a service cycle increases due to a larger pull frequency, the average power consumption increases due to the increase of transmission by each LMH. A larger pull frequency requires a greater number of data queries to be processed per second.

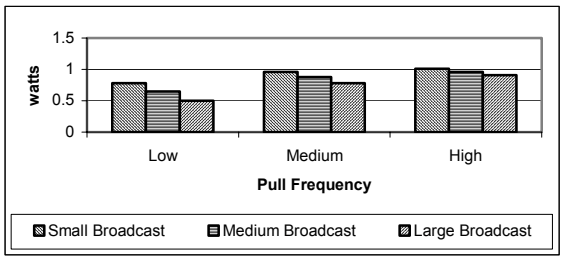


**Fig. 7.** Average Client Power Consumption

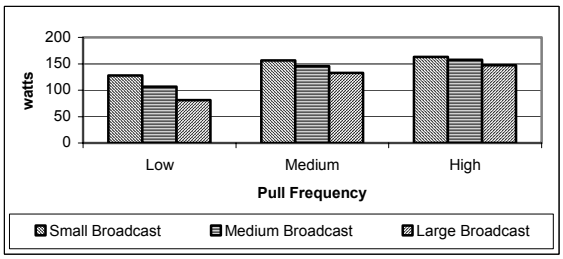


**Fig. 8.** Average Server Power Consumption

The average power consumption for SMHs is nearly at the receive level. Nearly two thirds of the SMHs were within the reach of a LMH transmission. The broadcast effectiveness suffered as a SMH was more likely to be within range of more than 1 LMH. The static portion of the broadcast transmission is then duplicative and lowers broadcast effectiveness. While effectiveness is lower, most clients are served. In this scenario the level of disconnection in the MANET is low as a large number of nodes occupy a small space. In fact, the 6 LMHs serve a population of 1000 SMHs. Because of this, the amount of time spent in data pull is much higher than the time spent in data push. Data pull is more expensive as each LMH responds to individual queries and routing requests. During data pull, LMHs serving a large number of SMHs may spend the majority of their time in transmit mode.

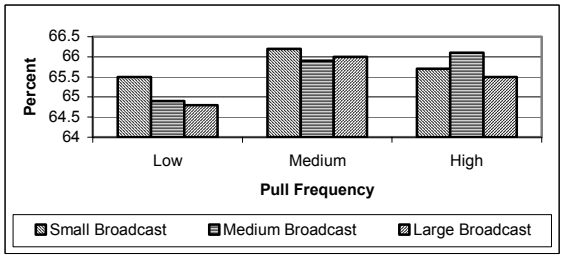


**Fig. 9.** Percentage of SMHs hearing a Data Broadcast

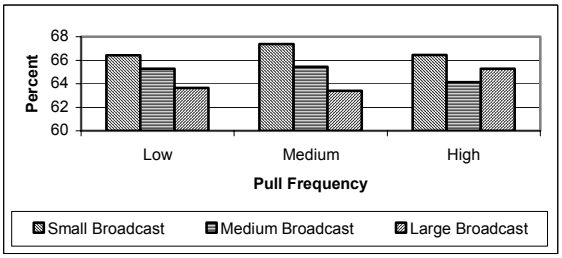


**Fig. 10.** Broadcast Effectiveness

Query efficiency is rather low. This can be accounted for in two ways. First, less than two thirds of the SMHs can make a data request. While two thirds heard a broadcast, the transmission range of a SMH is less than half of the transmission range of a LMH. Second, the large number of SMH served by each of the very few LMHs will be high.

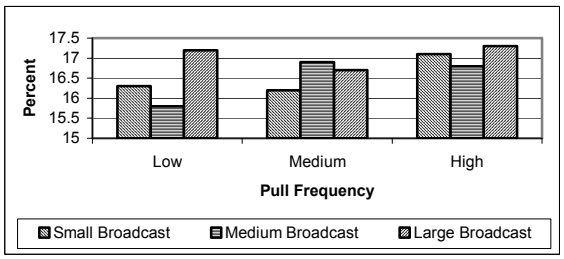


**Fig. 11.** Query Efficiency

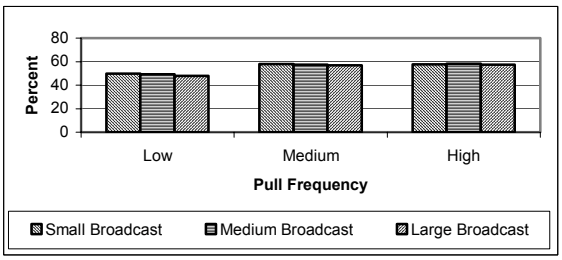


**Fig. 12.** Peer Efficiency

Perhaps the most interesting result from the simulation is the large number of similar results, regardless of broadcast size or query/peer frequencies.

## 5 Conclusions and Future Work

This paper presented a protocol that allows all three forms of MANET data communication, preserving power and accommodating limited bandwidth and mobility. The proposed protocol, TriM, compared favorably to the Leader

Selection MANET data communication protocol while providing the additional capability of peer-to-peer messaging. In the scenarios simulated, data query and peer messaging were reasonably successful and TriM performed well in simulation.

The development of additional MANET scenarios is needed. Some MANET applications suggested in the literature have parameters different from those used. Included in future work is the development of appropriate mobility models. When the movement characteristics of nodes within the scenario are better parameterized, it may be found that current protocols need additional modification. In addition to mobility models, the effect of increased transmission ranges should be investigated. The ability to increase coverage through data relay and greater node cooperation should be studied. Currently, no standard method exists for the study and evaluation of MANET data communication protocols. The development and acceptance of a standard benchmark is recommended. Further work on the protocol itself is in order. Adding real-time capabilities, directional antennas, variable power transmissions, etc. provide a list of items that can be added to a new or modified protocol.

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