Improving MANET Data Communication in Large Geographic Areas

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Abstract - A Mobile Ad-Hoc Network (MANET) is a group of wireless, mobile, battery-powered clients and servers that autonomously form temporary networks. Three data communication modes can be provided in a MANET: data broadcast, data query, and peer-to-peer messaging. Previously, the TriM data communication protocol (Tri-Modal communication) has been shown to be capable of providing all three data communication modes in both small (1km x 1km) and large (10km x 15km) areas. However, performance of the protocol was severely degraded as the size of the area served increased. In this paper we consider improvements to MANET clients and servers that better allow it to provide data communication services to nodes throughout larger geographic areas. Simulation shows that TriM is not only capable of providing power-aware and mobile-aware data communication services in larger geographic regions but that these services can be provided at a high level of availability.

1. Introduction

A MANET is a collection of mobile, wireless and battery powered servers and clients [7]. The topology of a MANET changes as nodes move. A MANET is a potential solution whenever a temporary network is needed and no fixed infrastructure exists. Example applications include the military scenario, which includes many nodes moving in a large geographic area without the benefit of a fixed power grid or wired network topology. Other potential uses include networks for temporary business purposes and networks serving disaster relief efforts.

MANETs differ from traditional mobile networks. In traditional mobile networks the servers, and potentially some clients, are stationary and powered by a fixed power grid. In addition, servers and some clients may be connected over a wired network. 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]. In a MANET, all clients and servers are wireless and battery powered.

Nodes (clients and servers) may not remain connected to the MANET throughout their life. To be connected to the network, a node must be able to hear the transmission of at least one other node on the network and have sufficient power to function. We assume a fixed transmission range. Network nodes (clients and servers) may operate in any of the three modes [10]. These are: **transmit –** this mode uses the most power, allowing transmission and reception of messages, **receive –** this mode allows the processing of data and reception of transmissions, and **standby –** in this mode, the CPU does no processing, transmitting or receiving.

Traditional mobile network research must address the limitations of the wireless bandwidth as well as the mobility and battery power of clients. MANET must also consider these issues for servers. This prevents the use of current traditional mobile network data communication protocols, which assume stationary servers with unlimited power.

Most MANET research has centered on routing issues [1][9]. Over the past few years, interest in data communication has been increasing [7][16][18].

The data communication research issues in MANET center around two areas. These issues are described in detail in [4]. The first area concerns the limitations of the environment (wireless, limited bandwidth, battery powered, mobile). The second area concerns the three ways in which MANET data communication may take place. Within this area, concerns due to data push, data pull and peer-to-peer communications exist.

Some work in MANET data communication has been scenario specific. In the work of Jung [11], location dependent queries in urban areas are addressed. Tang [14] adapts MANET data broadcasting to power controlled wireless ad-hoc networks. In these networks, servers have the ability to broadcast at one of several discrete power levels. Wieselthier, et al, have worked on MANET data broadcast. Their approach is the construction of a minimum energy tree rooted at the broadcast source [16]. The algorithms were tested and showed that by utilizing broadcast in a mobile environment, energy savings can be achieved. However, the networks tested were small and node mobility was not addressed. The cost of building the tree is considered negligible [16]. However, it has been shown that tree-based protocols do poorly when there is node mobility [8]. The problems of limited bandwidth, the need for tree maintenance, and node mobility also remain.

Two protocols to handle data push and a limited form of data pull within the MANET were proposed in [7]. They use 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 [7]. Data deadlines are used to determine which data requests to service. The protocols include a leader selection protocol. The leader coordinates the broadcast responsibilities of other servers in its region by determining which portion of the broadcast each server transmits. Between broadcast transmissions, clients are permitted to query the servers [7]. These algorithms have a potentially large overhead where less popular items may starve or be delayed while awaiting leader selection [7].

The second protocol includes the use of a popularity factor (PF). 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 [7]. An additional factor, Resident Latency (RL) also affects the PF. The PF decreases whenever request age exceeds the RL [7]. To localize data delivery, the lead server assigns each server the amount of data, but not which items, to broadcast [7]. In addition to leader selection costs, calculation of the PF and comparison to the RL add to the overhead.

Most current MANET data communication protocols have provided only one or two modes of data communication. TriM is a new protocol that has been designed specifically for the MANET environment. A complete description of the TriM protocol can be found at [3][5]. TriM has shown through simulation to be capable of providing all three modes of data communication in small 1km x 1km regions [5] as well as in larger 10km x 15km regions.

This paper extends the previous work on TriM by evaluating new conditions meant to improve data communication in the larger geographic areas.

2. Trim Data Communication Protocol

In this section we summarize the TriM data communication protocol. Due to space limitation, a complete treatment of the protocol including all parameters can be found in [3][5]. Figure 1 shows the four stages in a single iteration of TriM. The protocol will cycle through these stages repeatedly. Prior to the first iteration of the protocol, the network is initialized by setting all protocol parameters.

Synch Stage	**Data Push Stage** Data Broadcast	**Data Pull Stage** Data Request Peer-to-Peer	***Idle Stage***

Figure 1: TriM Data Communication Protocol

Data broadcast occurs in the data push stage and data query and peer messaging occur in the data pull stage. The synchronization stage allows servers/clients 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 effectively determines the frequency of data broadcast. This cycle repeats until the network is taken out of service or all nodes fail.

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 characteristics of that particular deployment. Network initialization involves a variety of parameters. These values are static throughout that MANET deployment. Each server and client independently monitors time and uses this to synchronization with other nodes.

TriM was simulated using the data parameters shown in Table 1. These are detailed in [3]. The AweSim simulation software [13] was used for this simulation study. AweSim is a general-purpose simulation tool that provides discrete event simulation of user defined networks [13].

TABLE 1: MANET Data Communication Simulation Parameters for Large and Small Geographic Areas

Parameter	**Value**	**Parameter**	**Value**
Bandwidth Server Client	 2 Mbps 100 Kbps	Server Power Dissipation Transmit Mode Receive Mode Standby Mode	 170 w 20 w 2 w
Transmission Range Server Client	 250 meters 100 meters	Client Power Dissipation Transmit Mode Receive Mode Standby Mode	 7 w 1 w 0.1 w
CPU Power Server Client	 1700 MIPS 100 MIPS	Mobility – (m/sec) Small Large	 0 to 1 0 to 20
No. of Nodes Server Small Server Large Client	 6 20 1000	Size of region (km) Small Large Simulation Time	 1 x 1 10 x 15 1 hour

As with any simulation, some assumptions must be made. It is assumed that each broadcast transmission contains up to 100 items, equally split between static and dynamic data items. It is further assumed that a client 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 20 data queries and 20 peer-to-peer messages per client per second. It is assumed that a client will send all data queries and routing requests to the closest server detected during synchronization.

The benchmark uses the following evaluation criteria [2]:

- **Average Power Consumption**: The average power consumed by clients and by servers.
- **Percentage of Coverage**: This measure the number of clients able to hear at least one data broadcast each service cycle.
- **Broadcast Effectiveness**: This is the ratio of items of interest in a broadcast to the total number of items transmitted. Only calculated for those clients able to hear a broadcast.

- **Query Efficiency**: The percentage of data queries that get served in one pass through the protocol.
- **Peer Efficiency**: The percentage of messages received during one pass through the protocol.

3. Simulation Results

Previously, simulation results have been reported for small geographic areas (1 km x 1 km) [5] and large geographic areas (10 km x 15 km) [3] using the benchmark parameters [2]. Simulation results are summarized in Table 2. Data communication degrades significantly as the size of the network area grows. Fewer nodes hear a data broadcast or participate in data query or peer communication activities. This is due to the size of the geographic areas when compared to the limited transmission ranges of the clients and servers.

TABLE 2: MANET Simulation Results for Large and Small Geographic Areas using Benchmark Parameters.

	Large Geographic Area	Small Geographic Area
Client Average Power	0.28	0.88
Server Average Power	8.88	145.21
Percent Client Hearing Broadcast	16.12	65.9
Broadcast Effectiveness	84.16	65.45
Query Efficiency	9.67	16.9
Peer Efficiency	33.2	57.4

One thing to note in the two scenarios simulated is that the number of clients within reach of a server never gets near 100% and peer efficiency and query efficiency are never high, getting lower as region size increases. This is true even though there are additional servers in the large geographic area. Two changes are investigated that improve these measures. We first increase the number of servers in each region, measuring the impact on data communication. We will then vary the transmission ranges of clients and servers to measure the change in data communication.

In Tables 3 and 4 we see the impact of increasing the number of servers in the large geographic area. In Table 5 and 6 the simulations were only run to 100 servers. In this scenario, the geographic area is only 1km x 1km. Having more than 100 servers did not seem reasonable.

TABLE 3: MANET Simulation Results for Large Geographic Areas using 20, 50 and 100 Servers.

	20 Servers	50 Servers	100 Servers
Client Average Power	0.28	0.14	0.13
Server Average Power	8.88	4.52	3.43
Percent Client Hearing Broadcast	16.12	29.42	40.68
Broadcast Effectiveness	84.16	63.83	33.29
Query Efficiency	9.67	17.04	32.01
Peer Efficiency	33.2	34.55	49.88

The results look promising. With 500 or 1000 servers we get a very high percentage of clients hearing a broadcast, having queries processed and peer messages sent and received. In addition, the power consumption rate for servers gets very low as a large percentage of time is spent in standby while other servers broadcast. There is a cost associated with this. If too many servers are put into service, the cost in time and money can be substantial. In addition, the length of the service cycle increases dramatically as the protocol specifies sequential transmission of data broadcasts. Clearly the number of transmissions heard by each client is also large and the broadcast effectiveness becomes quite small as duplicate items are heard from multiple broadcasts.

TABLE 4: MANET Simulation Results for Large Geographic Areas using 500 and 1000 Servers.

	500 Servers	1000 Servers
Client Average Power	0.14	0.18
Server Average Power	2.93	3.72
Percent Client Hearing Broadcast	96.00	99.75
Broadcast Effectiveness	1.22	0.41
Query Efficiency	87.33	95.56
Peer Efficiency	94.72	98.90

TABLE 5: MANET Simulation Results for Small Geographic Areas using 6, 10 and 20 Servers.

	6 Servers	10 Servers	20 Servers
Client Average Power	0.88	00.73	0.43
Server Average Power	145.21	143.01	137.98
Percent Client Hearing Broadcast	65.9	77.10	91.70
Broadcast Effectiveness	65.45	50.69	28.35
Query Efficiency	16.9	23.60	46.30
Peer Efficiency	57.4	61.80	73.15

TABLE 6: MANET Simulation Results for Small Geographic Areas using 50 and 100 Servers.

	50 Servers	100 Servers
Client Average Power	0.18	0.14
Server Average Power	130.74	128.85
Percent Client Hearing Broadcast	100	100
Broadcast Effectiveness	12.36	6.30
Query Efficiency	74.80	93.30
Peer Efficiency	87.40	96.65

Tables 7 and 8 show the impact of increasing transmission ranges for servers and clients in large geographic areas while Tables 9 and 10 show the impact of increased transmission ranges in small geographic areas. In the server 250 m. case, the client range is 100 m. This is the benchmark case. For the other cases, the client range is 50% of the server transmission range. The purpose of simulating varying transmission ranges is to see the effect of technological improvements. Except for the transmission ranges, other values are benchmark values.

TABLE 7: MANET Simulation Results for Large Geographic Areas with varied Transmission Ranges – Part I.

Transmission Ranges	Server - 250 m Client - 100 m	Server - 500 m Client - 250 m
Client Average Power	0.28	0.37
Server Average Power	8.88	11.04
Percent Client Hearing Broadcast	16.12	32.97
Broadcast Effectiveness	84.16	76.26
Query Efficiency	9.67	16.37
Peer Efficiency	33.2	51.48

TABLE 8: MANET Simulation Results for Large Geographic Areas with varied Transmission Ranges – Part II.

Transmission Ranges	Server - 1000 m Client - 500 m	Server - 2000 m Client - 1000 m
Client Average Power	0.41	0.42
Server Average Power	59.76	61.03
Percent Client Hearing Broadcast	59.16	87.26
Broadcast Effectiveness	53.86	24.80
Query Efficiency	32.97	60.69
Peer Efficiency	65.34	80.16

TABLE 9: MANET Simulation Results for Small Geographic Areas with varied Transmission Ranges – Part I.

Transmission Ranges	Server - 250 m Client - 100 m	Server - 500 m Client - 250 m
Client Average Power	0.88	0.89
Server Average Power	145.21	150.35
Percent Client Hearing Broadcast	65.9	97.20
Broadcast Effectiveness	65.45	30.43
Query Efficiency	16.9	65.60
Peer Efficiency	57.4	82.80

TABLE 10: MANET Simulation Results for Small Geographic Areas with varied Transmission Ranges – Part II.

Transmission Ranges	Server - 1000 m Client - 500 m	Server – 2000 m Client - 1000 m
Client Average Power	0.89	0.89
Server Average Power	154.12	154.65
Percent Client Hearing Broadcast	100	100
Broadcast Effectiveness	16.86	16.67
Query Efficiency	97.20	100
Peer Efficiency	98.60	100

4. Conclusions & Future Work

The simulation showed the behavior of the TriM protocol under benchmark conditions assuming random distribution of nodes in the simulation region as well as with varied numbers of servers and varying transmission ranges.

We see that that increasing the transmission range for clients and servers improves data communication rates. Increasing the number of servers also improves data communication rates. However, many servers are needed.

The simulations also show that with respect to power consumption, the protocol performed very well when the network was sparsely populated. Also, the behavior of the protocol allows coordinated effort by all nodes, reducing network collisions and the resulting retransmissions.

The simulations also show that in environments where a large number of clients have their data needs met by a small number of servers, data query becomes less energy-efficient and the cost to servers is greatly increased. Finally, the simulations showed that in sparsely populated regions, as represented by the large geographic area, network performance can be increased markedly through increasing transmission ranges. The varied transmission ranges appear to be a very good option. It should be noted that increasing the transmission range of a server or client does not increase the length of the service cycle or the amount of time spent in any of the various power modes.

The impact of additional node configurations, particularly new mobility models is an important area for future research.

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