Advance Mobile Ad-Hoc Data Communication Network

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Abstract— **Mobile Ad-hoc Networks (MANET) is an emerging area of research. Most current work is centered on routing issues. This paper discusses the issues associated with data communication with MANET database systems. While data push and data pull methods have been previously addressed in mobile networks, the proposed methods do not handle the unique requirements associated with MANET. Unlike traditional mobile networks, all nodes within the MANET are mobile and battery powered. Existing wireless algorithms and protocols are insufficient primarily because they do not consider the mobility and power requirements of both clients and servers. This paper will present some of the critical tasks facing this research.**

I. INTRODUCTION

A traditional mobile network consists of a fixed network of servers and clients, with a collection of mobile clients that move throughout the geographic area of the network. Within the mobile network, servers have unlimited power and communicate with mobile hosts over a wireless connection. Mobile clients may only communicate among themselves through a server. Among the issues in this type of network are client power consumption, connectivity of the network, and reachability of mobile clients from a server.

In contrast, a MANET is a collection of mobile servers and clients. All nodes are wireless, mobile and battery powered [9]. The topology can change frequently. The nodes organize themselves automatically, and can be a standalone network or attached to a larger network, including the Internet [2]. All nodes can freely communicate with every other node.

In addition to the issues associated with a mobile network, the power consumption and mobility of the server(s) must also be considered in a MANET.

Originally called Mobile Packet Radio, Mobile Ad-hoc Network (MANET) technology has been an important military research area [5]. This technology has practical use whenever a temporary network with no fixed infrastructure is needed. Other uses include rescue operations and sensor networks [13][18]. The support of these military and civilian uses often requires the presence of a database to store and transmit critical mission information such as inventories and tactical information.

There is one other crucial characteristic of a MANET. Traditional mobile networks involve the server in all data communication. MANET includes the traditional database capabilities of data push and data pull, but it also allows the clients to communicate directly with each other without the involvement of the server, unless necessary for routing [6][13].

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II. MANET Architecture

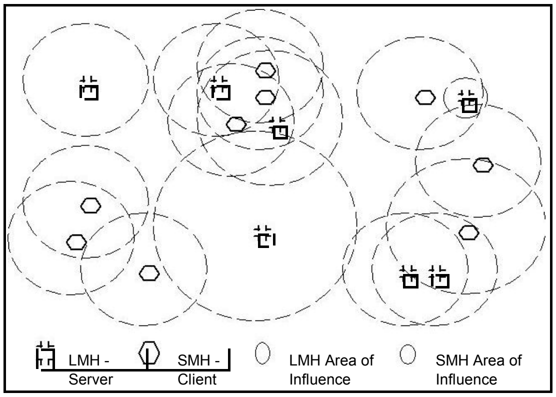
The nodes in a MANET can be classified by their capabilities. A Client or *Small Mobile Host (SMH)* is a node with reduced processing, storage, communication, and power resources. A Server or *Large Mobile Host (LMH)* is a node having a larger share of resources [9]. Servers, due to their larger capacity contain the complete DBMS and bear primary responsibility for data broadcast and satisfying client queries. Clients typically have sufficient resources to cache portions of the database as well as storing some DBMS query and processing modules [9].

As both clients and servers are mobile, the speed at which the network topology changes can be rapid. A variety of techniques have been proposed to assist in the routing tasks of MANET. New protocols were necessary as the protocols for fixed infrastructures and static networks do not perform well when node mobility is included [16]. A global routing structure is also not useful in MANET due to its dynamic topology and need for distributed control [16]. Work on routing is ongoing and is coordinated through the Internet Engineering Task Force (IETF) [3].

MANET characteristics include a preference for reactive (on-demand) routing, unpredictable and frequent topology changes and distributed control [18]. The primary MANET limitations remain limited bandwidth and battery power [18].

Nodes may not remain connected to the network 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 Figure 1, a few nodes of a MANET are shown graphically. It is important to note that each node has an area of influence. This is the area over which its transmissions can be heard. A LMH will initially have a larger area of influence as it generally has a more powerful battery. As the power level decreases, the area of influence of any node will shrink. This is due to the fact that the power available to broadcast is reduced.



Network nodes may operate in any of three modes that are designed to facilitate the reduction in power used [12][19]:

- Active Mode (or Transmit Mode): this is the mode using the most power. It allows both the transmission and reception of messages and consumes 3000 to 3400 mW [19].
- Doze Mode (or Receive Mode): the CPU is capable of processing information and is also capable of receiving notification of messages from other nodes and listening to broadcasts. 1500 to 1700 mW are consumed in this mode [19].
- Sleep Mode (or Standby Mode): the CPU does no processing and the node has no ability to send/receive messages. The node is inactive and consumes only 150 to 170 mW [19]. This mode allows a node to turn itself off for short periods of time without requiring power-up or re-initialization.

A node with no remaining power, or one that is off, is not currently a part of the network.

It is clear from the description and Figure 1 that a node may not be reachable by another node (LMH or SMH). In other words, nodes may become disconnected from the entire network. When moving back in range of other nodes, they will become re-connected. Conversely, a node may be reachable by several LMHs or SMHs. The potentially rapid and regular reconfiguration of the network topology is routine with the MANET.

III. Current Data Communication Research in Mobile Databases

Data communication research in mobile databases is limited to situations where only clients are mobile and battery powered. These studies are concerned with ways to maximize client battery life by improving either the organization of the data broadcast or the selection of the broadcast contents. Below is a brief discussion of representative papers in this area.

Aksoy, et. al. [4] present a large-scale on-demand broadcast model called R*x*W (Requests times Wait). At each broadcast tick, the server chooses an item to broadcast based on the number of request and the amount of time the original request has been waiting. The overhead for large databases is significant in both time and space [9]. In addition, the server may be constantly in active mode, as the server power level is not an issue. There is a power cost associated with constant client queries.

Guo, et. al. [10] also work on improving the responsiveness of database service. In their approach, the server maintains a list of popular and less popular items. The popular items are continuously broadcast. If a less popular item is needed, a client may request it. This interrupts the broadcast, which continues with the data broadcast after serving the request. The server never stops broadcasting, consuming power.

Yajima, et. al. [22] and Grassi [8] approach the problem differently. They try to improve database service by the organization and use of the broadcast. Yajima [22] builds broadcasts where highly correlated items are found together in the broadcast, minimizing the number of times a client must access the broadcast. Grassi [8] uses prefetching related items into the client cache so that they will be available locally if needed. While prefetching may shorten the time a client needs to access a data item, prefetching wastes power and space through accessing and storing broadcast items that may not be needed. The benefits from a correlated broadcast require a constant processing and broadcasting by the server, leaving it constantly in active mode.

While addressing the issues of broadcast size, organization and content, the traditional mobile broadcast methods proposed fail to deal with server mobility and power limitations.

IV. Current Data Communication Research in Mobile Ad-Hoc Databases

A MANET may include data pull, data push and peer-to-peer communication. No research has been done which includes all three forms of communication. However, data push and data pull have been addressed to varying degrees. Below the recent work in Mobile Ad-Hoc data communication is addressed.

Wieselthier, et. al. have been working together on MANET broadcast issues. Their approach is the construction of a minimum-energy tree rooted at the broadcast source [20][21]. 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 [20].

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 [20]. 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 [20]. This would be the case for stationary nodes. However, stationary nodes would be the exception in MANET. They accommodate "movement" with the observation that increasing transmitter power will allow them to reach nodes in new locations [21]. No potential interference between broadcasts and no need to rebuild the tree once created are considered.

The restrictions and assumptions are limiting. In addition, tree- based protocols do poorly with node mobility [10]. 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 in [9]. 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 [9].

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 [9]. This is a soft real-time system. There are deadlines for data delivery. The deadlines were used to determine which data request to service although no penalty for missing a deadline was mentioned.

There is a leader protocol that selects the server in a region with the greatest remaining power. The leader coordinates the broadcast responsibilities of other servers in its area of influence [9]. 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 [9]. No server transmits the entire broadcast unless it is the only server in a region

After the conclusion of broadcasting, clients are permitted to query the servers. After the time period for queries, the broadcast cycle repeats [9].

This initial algorithm has a potentially large communication overhead, servers with no clients still broadcast, and less popular items may starve or be broadcast too late [9].

The second algorithm utilizes a popularity factor (PF), as suggested by Datta et. al. [7]. 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 [9]. 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 [9]. The PF decreases whenever a request exceeds the RL value [9]. 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 [9]. Finally, to localize data delivery, the lead server assigns each server the amount of data to broadcast but not the items to broadcast [9].

To deal with insufficient power levels, the servers rebroadcast the previous index and broadcast if they have insufficient power to build a new broadcast [9]. It is not clear why broadcasting old information is preferable to no broadcast at all.

This approach is still not sufficient as servers can be assigned a broadcast larger than their power levels would permit. Power and bandwidth is also wasted with duplication.

V. Research Issues

The data communication research issues in MANET databases center around two areas. The first area concerns the limitations of the environment (wireless, limited bandwidth, battery powered). The second area concerns the many ways in which data communication may take place.

Environmental Limitations

Power Consumption

Power consumption is a concern in any mobile network. However, in traditional mobile networks, only the power needs of the clients are considered. Here, the power of the server, which provides DBMS data services, is perhaps more important as it provides DBMS services to potentially many clients. This is the one overriding issue [17]. Its parts are:

- Are power settings broadcast for servers and clients? If so, how often?
- How do server power levels affect broadcast assignments?
- What should be done with a LMH/SMH with a low power level.

A server's power setting is an important input into the entire process. Servers with the greatest power availability may be expected to perform the most work. If this information is broadcast, power is consumed.

Methods to minimize client power drain are also important but are addressed in existing mobile network research.

Broadcasting is both time and energy conscious [15]. A carefully coordinated set of broadcasts can reach a large number of clients who only have to listen to get the information they need. Only if the information needed is not broadcast does a client need to query the database.

Timing

Regardless of the method of communication used, access time and tuning time must be considered. Tuning time is the measure of the amount of time each node spends in Active Mode. This is the time of maximum power consumption for a client. Because of that, tuning time minimization is an important goal.

Access time measures the responsiveness of the algorithm. Access time refers to the amount of time a client must wait to receive an answer to a database query. If Access Time is too long, the client may no longer be reachable from the server assigned to broadcast the information. Power is wasted if broadcast information is missed and must be requested.

Data integrity

With data integrity, we are concerned with the accuracy of information stored at each node: server and client alike. This problem occurs as servers and clients move in and out of contact.

Acknowledgement messages are not appropriate in a MANET as mobility makes receipt unreliable and extra bandwidth and power are consumed.

Data replication is an important consideration. If the database is fully replicated among all mobile servers, additional power is consumed to maintain the databases. If full replication is not required or possible, other data integrity issues exist.

While data replication may not exist for an entire network, it may be possible to maintain it in disjoint partitions within the network. Partitioning of a network or database is either carefully designed and reasonably static or is considered a failure condition [14]. As servers are mobile, partitions would be necessarily dynamic. Partitioning would also not be considered a failure in a MANET, but would be normal. Either method or level replication would add some amount of overhead to the network.

The end result is that the database stored at each server may not be consistent with one another. As database updates are made, not all servers are guaranteed to receive the updates in a timely fashion.

Nodes become disconnected for a variety of reasons. This may be due to location or lack of power. The dynamic nature of MANET makes maintaining the data a challenge. Multiple versions of the same information may exist throughout the network. When portions of the network become separated for a time, keeping data accurate may become impossible.

Data Broadcast (Data Push)

Of all the MANET activities, data communication remains one of the high power consumption activities. When broadcasting, each node listening to a broadcast consumes nearly half as much power as is consumed by the broadcaster [12].

Traditional mobile network protocols [1][4] assume that the clients can regularly submit requests to the DBMS servers. Traditional methods [4] also use frequency of request when building broadcasts. There is nothing efficient about multiple clients individually requesting the same data item. It is also not energy efficient for servers to unicast the same data individually to several clients. It is important to minimize data requests, saving power at both the server and client. Current methods do not minimize client requests.

It is important to keep in mind that while broadcast is energy efficient when working with multiple nodes; it is not sufficient when a large number of data items must be delivered [10]. Data pull alone is also not sufficient [10]. Both methods, used appropriately, are necessary to achieve the greatest energy efficiency [10].

Broadcast Content

The size and contents of a broadcast affect power consumption and the frequency of data queries. If the broadcast is too large, unnecessary information may be broadcast. If too little information or the wrong information is broadcast, on-demand requests increase. In both cases, Access Time also increases. Traditional mobile networks solve this problem through building broadcasts based on frequency of queries [10] wasting client power or by broadcasting continually [4] wasting server power.

Mobile network research shows that an index can minimize the amount of time clients must remain active, accessing the broadcast [11]. The tradeoff is that the index must also be broadcast. The small amount of energy needed to broadcast the index may offset the large amount of energy needed by many clients to listen to the entire broadcast.

- How often the contents of a broadcast are built/changed.
- Node's data needs – as determined from data requests not served through data-on-demand or peer-to-peer communication.
- What criteria are used to determine what is included in the broadcast?
- Should an index be used as part of the data content?

Broadcast Allocation

If multiple servers exist in an area, who broadcasts what? The methods proposed in [9] assume a leader that coordinates the work of the server group. This is an attempt to save power by sharing the load. But must a leader be selected? Perhaps each server can coordinate based on individual knowledge of area servers and clients.

In addition to the allocation of broadcast content, the timing of broadcasts is critical. In many ways, MANET broadcasting is like the telephone party line or a bus network topology. If several servers attempt to broadcast simultaneously, there will be a collision and the broadcast of all will be garbled. This is a waste of time and power for both the servers and the clients listening to the broadcasts. If using a lead server makes broadcasts assignments, it is possible for a node's assignment to be larger than it can accommodate, based on the node's remaining power. This is not an efficient allocation. A portion of the broadcast will not be sent and that LMH will disappear from the network due to running out of power.

Broadcast Frequency

Too frequent broadcasts waste power unnecessarily. Too infrequent broadcasts lead to increased client requests, wasting their power. The frequency of broadcasts will be a function of server power levels and the data request frequency of clients. Frequency of broadcasts affects both Tuning Time and Access Time.

Broadcast Reasonableness

This is a question of whether or not to even broadcast. If no clients are in the broadcast area, a broadcast is meaningless and a waste of power. If only a few are in the area of influence, handling data needs interactively may be more efficient. A method to identify and track nodes in a server's area of influence is necessary.

Data-on-Demand (Data Pull)

- Should a request be added to the next broadcast or served immediately?
- Should a client be prohibited from querying for the same data as another client in the same area or should it just wait for data service?
- Does the server need to know how many clients want a piece of data to determine data importance?
- How is data aged so that all requested data is eventually broadcast?
- Is it important to serve data requests even after a certain amount of time has elapsed?
- When a SMH leaves an area, do we forward the data service request – or do we rely on the SMH to determine it is in a new cell and know it must re-request the data?
- How do we forward service requests in the network?

The issues here center on client data needs that are not met by the data broadcast. If the broadcast does not satisfy the needs of a client it must obtain the data from a server (data-on-demand) or from another client (peer-to-peer).

Which method a client uses will depend on who has the most recent data. What factors determine the best data source must be investigated. While satisfying the data needs of the client, we must remain sensitive to power consumption and mobility issues

Peer-to-Peer Communication

When the server does not satisfy the data needs of the SMH through broadcast or data-on-demand, a client may communicate directly with another client that has the needed data. The issues here include the role of the different nodes in this communication, and determining who has the data. Existing data broadcast algorithms proposed in the MANET literature do not address peer-to-peer communication.

- Should the client be limited in the number of peer-to-peer requests they make?
- How does the server know it needs to route a request?
- Should peer-to-peer be limited to certain types of requests?
- If a request is not serviced in time, should it be added to the next broadcast?

Conclusions and Future Work

Data communication is an important topic that needs to be addressed when designing database systems in MANET environments. This topic involves far more than network routing. In addition, existing mobile protocols are insufficient. They are not geared towards the specialized needs of a MANET.

The areas of concern within MANET data communication are raised. Future research will need to begin to address these issues. Along with these issues, standardized benchmarks and criteria for evaluation must be established so that proposed protocols and methods can be legitimately compared.

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