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Wireless Communication Networks – A Study & Emergence of Multipath Dissemination

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Abstract: **Mesh topologies are large scale peer-to-peer systems that use low-bandwidth wireless links to achieve the application objectives. The quality of service in such system is known to decrease as scale increase. Uniform spreading algorithm is spreading messages over all the shortest paths. This is a straightforward strategy where the source, as well as each intermediate node along every path in the contour, sends successive messages in a round-robin fashion. Uniform spreading algorithm shows that the nodes along one of the paths will always handle shortest paths more messages than the nodes along other paths. Optimal spreading algorithm is effectively utilize all the available shortest paths and spreading the messages in balanced load. Optimal technique characterize the set of shortest paths between a pair of nodes in regular mesh topology and derive rules using this characterization, it effectively spread the messages over all the available paths to improve QOS.**

Key words **- Wireless Network, Communication, Routing Protocols, Mesh topology.**

I. INTRODUCTION

Mesh networking is a type of networking where in each node in the network may act as an independent router, regardless of whether it is connected to another network or not. Mesh networks differ from other networks in that the component parts can all connect to each other via multiple hops, and they generally are not mobile. Mesh networks can be seen as one type of ad hoc network. Wireless mesh networks were originally developed for military applications and are typical of mesh architectures. Over the past decade the size, cost, and power requirements of radios has declined, enabling more radios to be included within each device acting as a mesh node. The additional radios within each node enable it to support multiple functions such as client access, backhaul service, and scanning (required for high speed handover in mobile applications).

In the recent years the deployment of WMNs has been looked upon as an upcoming and promising step towards the goal of ubiquitous broadband wireless access. WMNs are interesting not only in the context of small community networks and neighborhood networks, but also in the area of enterprise-wide networks or wireless backbone networks that can be established in an ad hoc manner, e.g. in disaster recovery scenarios.

Providing QoS[6][8] in these networks is a challenging task mainly because there is no central device controlling the medium access. Mechanisms to support QoS in WMNs should be designed and deployed.

Multihop communications [7] are necessary in such systems to send messages from any source to any destination. For example, intermediate nodes must forward messages to a monitoring station from nodes that cannot communicate directly with the monitoring station. Routing protocols are used extensively in wired and wireless networks to support multihop communication. Such protocols construct and maintain routing tables at each node by relying on system wide unique node identifiers. When the number of nodes is very large, such as in sensor networks, it is not feasible to use such identifiers. Several techniques, called dissemination methods, were developed at the network layer to regulate the flow of messages between nonadjacent nodes without relying on unique node identifiers or constructing routing tables using these identifiers.

In many highly engineered systems, one can assume that the nodes have fixed relative locations. Often, the systems are designed to overlay on an underlying grid. We address the issue of how to effectively utilize all the shortest paths available. Since the resulting methods amount to a node making local decisions on how to distribute messages among its immediate neighbors, without having to dynamically construct any routing tables, we refer to this method of forwarding messages as dissemination in spite of the fact that nodes are identified by their global coordinates in the underlying 2D Basegrid.

In section 2, we discuss the previous works done on enhancing QoS in Multipath Mesh networks. In section 3 we discuss about the network architecture that helps for better understand the later issues. We present uniform spreading in section 4 and optimal spreading in section 5. Section 6 concludes the paper.

2. RELATED WORK

Multihop wireless networks evolved to adapt to different uses and may be implemented in many distinct ways. Different from classical ad hoc networks, most applications of WMNs are broadband services with heterogeneous QoS requirements. Thus, in addition to end-to-end transmission delay and fairness, more performance metrics, such as delay jitter, aggregate and per-node through put, and packet loss ratios, must be considered by communication protocols.

Lower and upper bounds for ad hoc network capacity are derived in [2], where an important implication is pointed out as the guideline to improve the capacity of ad hoc networks: *a node should only communicate with nearby nodes.* To implement this idea, two major schemes are suggested in [2]:

• Throughput capacity can be increased by deploying relaying nodes.

• Nodes need to be grouped into clusters.

In other words, communication of a node with another node that is not nearby must be conducted via relaying nodes or clusters. However, considering a distributed system such as ad hoc networks or WMNs, clustering nodes or allocating relaying nodes is a challenging task.

The implication given in [2] can also be reflected in [3]. The scheme proposed in [3] increases network capacity of ad hoc networks by utilizing the node mobility. A source node will not send its packets until the destination node gets closer to it. Thus, via the node mobility, a node communicates only with its nearby nodes. This scheme has a limitation: the transmission delay is rather large and the required buffer for a node may become infinite.

The analytical approaches in [1, 2] have significantly driven the research progress in wireless network capacity. One limitation of these approaches is that the networking protocols have not been appropriately captured. Different medium access control, power control, and routing protocols significantly impact the capacity of a wireless network. However, in the analytical approaches [1, 2], they are only represented by oversimplified models.

Another limitation of existing analytical approaches [2] is that the theoretical capacity bounds are derived based on the asymptotic analysis. These results, however, do not reveal the exact capacity of a network with a given number of nodes, in particular when the number is small. The reason is that the assumptions about the network size or node density in the asymptotic analysis do not match the actual scale of any WMNs; neither network size nor node density will go infinite, no matter how a WMN is deployed. Moreover, due to the differences between WMNs and ad hoc networks, the analytical results of ad hoc networks may not be directly applicable to WMNs. Thus, new analytical results need to be derived for WMNs.

Despite the availability of many routing protocols for ad hoc networks, the design of routing protocols for WMNs is still an active research area. The main objectives of using multi-path routing are to perform better load balancing and to provide high fault tolerance. Multiple paths are selected between source and destination. When a link is broken on a path due to a bad channel quality or mobility, another path in the set of existing paths can be chosen. Thus, without waiting to set up a new routing path, the end-to-end delay, throughput, and fault tolerance can be improved. However, given a performance metric, the improvement depends on the availability of node disjoint routes between source and destination. Another drawback of multi-path routing is its complexity.

The impact of performance metrics on a routing protocol is studied in [4] where link quality source routing (LQSR) selects a routing path according to link quality metrics. Three performance metrics, i.e., expected transmission count (ETX), per-hop RTT, and per-hop packet pair, are implemented separately.

The performance of the routing protocol with these three performance metrics is compared with the method using the minimum hop-count. For stationary nodes in WMNs, ETX achieves the best performance, while the minimum hop-count method outperforms the three link quality metrics when nodes are mobile. This result illustrates that the link quality metrics used in [4] are still not enough for WMNs when mobility is concerned.

3. Network Architecture

The architecture of WMNs can be classified into three types:

3.1. Infrastructure/Backbone WMNs

In this architecture, mesh routers form an infrastructure for clients. The WMN infrastructure/backbone can be built using various types of radio technologies, in addition to the mostly used IEEE 802.11 technologies. The mesh routers form a mesh of self-configuring, self-healing links among themselves. With gateway functionality, mesh routers can be connected to the Internet. This approach, also referred to as *infrastructure meshing*, provides a backbone for conventional clients and enables integration of WMNs with existing wireless networks, through gateway/bridge functionalities in mesh routers. Conventional clients with an Ethernet interface can be connected to mesh routers via Ethernet links. For conventional clients with the same radio technologies as mesh routers, they can directly communicate with mesh routers. If different radio technologies are used, clients must communicate with their base stations that have Ethernet connections to mesh routers.

3.2. Hybrid WMNs

This architecture is the combination of infrastructure and client meshing. Mesh clients can access the network through mesh routers as well as directly meshing with other mesh clients. While the infrastructure provides connectivity to other networks such as the Internet, Wi-Fi, WiMAX, cellular, and sensor networks, the routing capabilities of clients provide improved connectivity and coverage inside WMNs.

The characteristics of WMNs are outlined below, where the hybrid architecture is considered for WMNs, since it comprises all the advantages of WMNs:

- WMNs support ad hoc networking, and have the capability of self-forming, self-healing, and self-organization.
- WMNs are multi-hop wireless networks, but with a wireless infrastructure/backbone provided by mesh routers.
- Mesh routers have minimal mobility and perform dedicated routing and configuration, which significantly decreases the load of mesh clients and other end nodes.
- Mobility of end nodes is supported easily through the wireless infrastructure.
- Mesh routers integrate heterogeneous networks, including both wired and wireless. Thus, multiple types of network access exist in WMNs.
- Power-consumption constraints are different for mesh routers and mesh clients.
- WMNs are not stand-alone and need to be compatible and interoperable with other wireless networks.

Therefore, WMNs diversify the capabilities of ad-hoc networks instead of simply being another type of ad hoc network. These additional capabilities necessitate new algorithms and design principles for the realization of WMNs.

4. SPREADING TECHNIQUES

4.1. Uniform Spreading: The first strategy we consider for spreading messages over all shortest paths will be called Uniform Spreading. This is a straightforward strategy where the source, as well as each intermediate node along every path in the contour, sends successive messages in a round-robin fashion to all its immediate neighbors in the contour. We present this algorithm and show that the nodes along one of the paths will always handle more messages than the nodes along other paths whenever this strategy is used.

Given below is the algorithm for uniform spreading. We note that in the algorithm both msgCount and ngbrs are dependent on the source-destination pair. We need separate counters for each source-destination pair. If the first packet in a batch contains the total number of packets in that batch, then we know how long to maintain the counters.

```
Let ngbrs[] be neighbors of node n_i in the contour.
Let d be the number of neighbors of ni in the
contour.
Let msgCount be a local variable in n_i.

Initially msgCount = 0;
Foreach intermediate node n_i in a contour {
        Receive m;
        Send m to ngbrs[msgCount mod d];
        msgCount++;
                }
```

4.2. Optimal Spreading

We now present an algorithm for spreading the messages so that all the available paths are effectively utilized. Recall that a row is a collection of nodes in the contour that are at the same distance from the source. Let w be the number of nodes in a row of a contour. We refer to w as the width of the row. If the source sends M messages and if every node in every row handles M/w messages, then we can say that the spreading is the best in the sense that all available paths are effectively used. This is the criterion of optimality that we choose.

Our algorithm for optimal spreading is given below. In the algorithm, the array *ngbrs[]* keeps track of the relevant neighbors for any node. The middle node in a row has two relevant neighbors in the next row that have the same label.

Intuitively, the nodes in the expansion region spread messages over the available paths, the nodes in the propagation region do not spread messages and propagate them along a single path, and the nodes in the contraction region coalesce messages from multiple paths. Our objective is to ensure that all the nodes in every row of a contour handle roughly the same number of messages.

To implement optimal spreading in practice, in more general situations, one can affect the spreading of messages in the desired ratio by using a randomized strategy that chooses the neighbors with the proportional probabilities. Then, the above result of equitable distribution of load holds in an expected sense.

4.3. Perfect Spreading

We introduce Perfect Spreading where the decision of selecting the intermediate nodes handling the spreading is made dynamically. Here in Optimal Spreading, the data ratio is very less compared to Uniform Spreading. But in Uniform Spreading, the data handled by each node is very high. In Perfect Spreading, we try to increase the data received by the destination, and reduce the data handled by each node. This makes the spreading perfect. We dissimilate the packets in two alternate routes to the intermediate nodes. The intermediate nodes select their consecutive two other nodes and send the data to them. Even because of congestion problems or bandwidth limitations, if the data is not reached to one node, it can be handled by the other node. This avoids retransmission and increases the data received at the destination.

```
let ngbrs[.] be the neighbors of n_p ∈ N.
let n_p be in row m that has width w.
let msgCount be a local variable.

initially msgCount := 0;

ngbrs[.] = null;
if p ≠ ⌊w/2⌋ + 1 then {
  ngbrs[0] = n_p^{m+1};
  if n_p ∈ expansion region then {
    ngbrs[1] = n_{p+1}^{m+1};
  } else if n_p ∈ contraction region then {
    ngbrs[1] = n_{p-1}^{m+1};
  }
} else {
  ngbrs[0] = n_{⌊(w+2)/2⌋+1}^{m+1};
  ngbrs[1] = n_{⌊(w+2)/2⌋}^{m+1};
  ngbrs[2] = n_{⌊(w+2)/2⌋}^{m+1};
}

foreach node n_p in the expansion region {
  receive m;
  msgCount++;

  if p ≠ ⌊w/2⌋ + 1 then {
    // all nodes except the middle node
    send messages to ngbrs[0] and ngbrs[1]
      in the ratio w + 2 − 2p : 2p;
  } else {
    // the middle node
    send messages to ngbrs[0], ngbrs[1], and ngbrs[2]
      in the ratio 1/(w+2) : 1/(w(w+2)) : 1/(w(w+2));
  }
}

foreach node n_p in the propagation region {
  // forward messages to one neighbor on next row
  receive m;
  send m to ngbrs[0];
}

foreach node n_p in the contraction region {
  receive m;
  msgCount + +;

  if p ≠ ⌊w/2⌋ + 1 then {
    // all nodes except the middle node
    send messages to ngbrs[0] and ngbrs[1]
      in the ratio w − 2p : 2(p − 1);
  } else {
    // the middle node sends all messages to the
    // middle node in the next row
    send m to ngbrs[1];
  }
}
```

As we follow Optimal Spreading technique while transmission of data, the number of data packets handled by each node is reduced. From the results obtained by simulating in NS2, it can be inferred that this method of spreading can be called as perfect spreading.

5. Simulation Results

The simulation is done in NS2. The three techniques Uniform Spreading, Optimal Spreading, and Perfect Spreading are run on same scenarios and the results are obtained. The three techniques are compared with respect to the data received at the destination node, and the data handled by each node in the network.

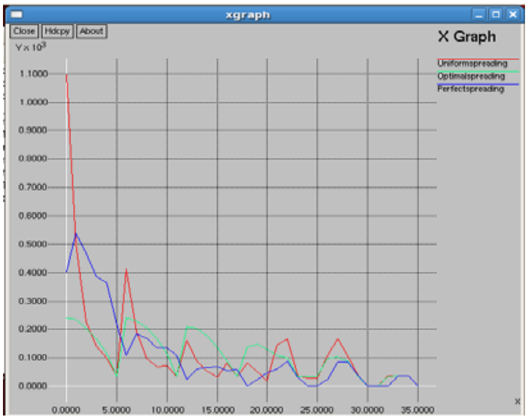

Figure 1. The data received at each node.

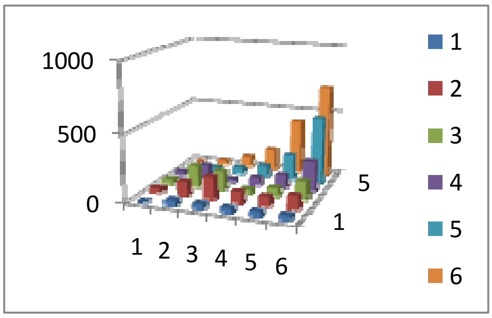

Figure 2. Data handled by each node in Unifrom Spreading

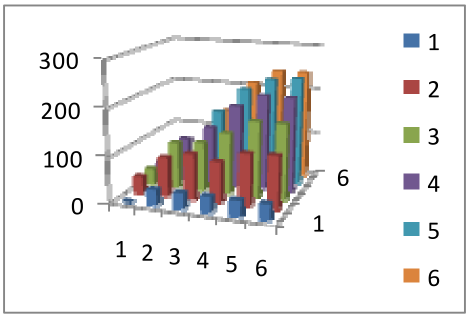

Fig 3. Data handled by each node in Optimal Spreading

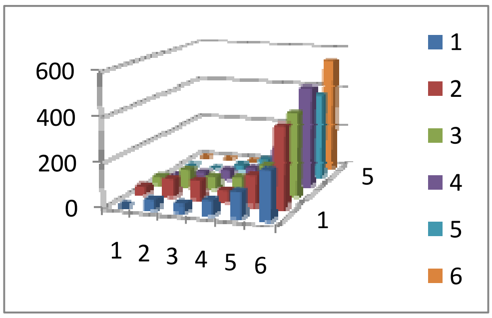

Figure 4. Data handled by each node in Perfect Spreading

6. Conclusion

Many future engineered systems that are based on peer-to peer-connected mesh topologies are likely to have multiple paths between a pair of nodes. We defined a contour as the union of all shortest paths between a pair of nodes. Using a regular topology, we proved that when the messages are spread uniformly over the paths in a contour, nodes along one path handle more messages than other messages. We presented an optimal strategy for spreading messages in such systems, and our results demonstrate the effectiveness of the spreading strategy.

To achieve optimal dissemination, some nodes must disseminate the messages over the available paths, and other nodes use only one of the available paths. Identifying these sets of nodes in general topologies is an interesting problem. In the future, the optimal dissemination techniques can be enhanced to improve QoS, mitigate interference, reduce hotspot effects, and design next-generation monitoring and surveillance systems based on wireless mesh topologies. .

From the results obtained by simulating in NS2, it can be inferred that the Perfect Spreading obtained an increase of 75% in data received by the destination, and considerable decrease of data handled by the each node.

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