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WIRELESS MESH NETWORKS: ROUTING CHALLENGES AND ADDRESSING UNFAIR BEHAVIOR AMONG NODES - A REVIEW

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Abstract

Wireless Mesh Networks (WMNs) are one of the key technologies which will dominate wireless networking in the next decade. To realize this vision, it is imperative to provide efficient resource management (buffer space, and bandwidth). Resource management encompasses a number of different issues, including unfairness in throughput, delay, and routing challenges. To have a clear and precise focus on throughput behavior in WMN, a simple example is described to study unfairness behavior and clearly understand throughput drop, and concept of bottlenecking node. This can serve as the basis for deriving the key design features for addressing the unfairness amongst throughput and delay in wireless mesh nodes. This paper could help to guide and refocus future works in this area.

INTRODUCTION

A wireless mesh network is a type of wireless networks in which each node can communicate directly with one or more peer nodes, is a form of ad hoc network that form mesh of wirelessly interconnected nodes [1]. Wireless Mesh Networks WMN is a new broadband internet access technology that draws a significant attention these days.

Many companies, such as Nokia, Microsoft, Motorola and Intel [2], are actively promoting wireless mesh networks as a full IP solution. Initial field tests have demonstrated WMN's tremendous potentials and market value. [3]The difference between these type of networks and conventional networks is the nature of packet movements, which is always from the clients to the gateway node or vice versa in Wireless Mesh Networks; whereas in other ad-hoc networks is between arbitrary pair of network nodes [4].

Wireless Mesh Network is a multi-hop network in which each node operates not only as a host but also as a router, forwarding packets on behalf of other nodes that may not be within direct wireless transmission range of their destinations. Each mesh node in the network has to be able to forward the traffic flows more than one that is of self and of other nodes. The traffic flow from self is called local traffic flow, whereas traffic flow from other nodes is called relayed traffic flow.

The end-to-end unfairness results from the waiting of the packet in the queue. The packets are buffered before they are transmitted. Traffic flows achieve different throughput at the destinations because of the different waiting period at each node. This delay sum up along the flow path and is higher in some of the traffic flows than other. [5]

Wireless mesh networks offer advantages over other wireless networks; these include easy deployment, greater reliability, self-configuration, self-healing, and scalability [6]. By addressing the unfairness issue and providing demand based fairness amongst various traffic flows will certainty realize these stated advantages.

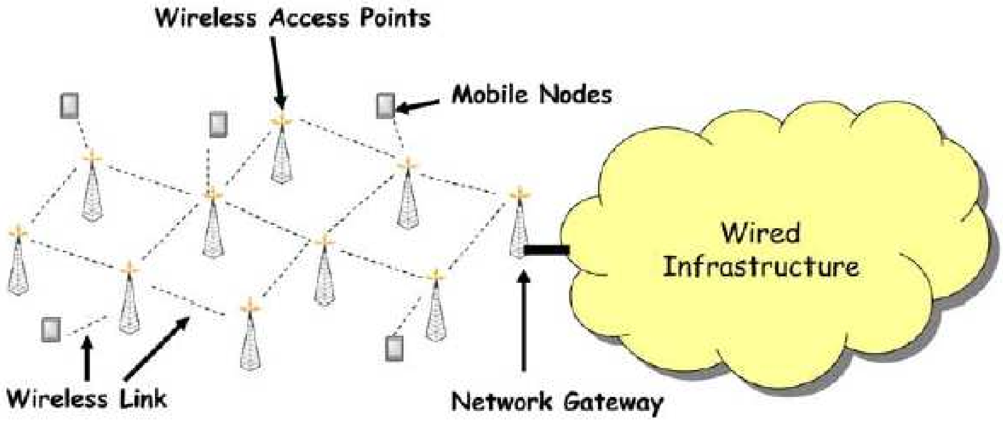


Figure1: Wireless Mesh Network Components: Mobile Nodes, Wireless Link, Wireless Access Points and Network Gateway [2]

NETWORK LAYER ISSUES

WMNs share many common features with ad hoc networks, therefore routing protocols developed for ad hoc network generally can be adapted for WMNs.

For example, mesh routers developed by Firetide Networks [7] which uses topology broadcast based on reverse path forwarding protocol , Microsoft Mesh Networks [8] which are based on dynamic source routing and many other companies use routing protocol based on AODV (Ad hoc on demand distance vector) algorithm. AODV is also major holding block in IEEE802.11s [6].

The design of routing protocol for WMNs is still an area of an active research for several reasons [6].

These reasons are:

1) New routing metrics need to be discovered and utilized to improve the performance of the routing protocols.

2) For MANETs, the major concern are high mobility in all nodes, complicated procedures are required to support such mobility. However mesh routers usually have minimal mobility.

3) The routing protocols for multi-hop wireless network treat underlying MAC layer protocol as transparent layer to routing. However the cross layer interaction must be considered in order to enhance the performance of WMNs.

4) The requirement of power efficiency is much different in WMN when compared to Mobile ad hoc networks. Thus routing protocol designed for mobile ad hoc network may not be appropriate for WMNs.

ROUTING CHALLENGES

A routing protocol may be visualized as an optimization problem. For any given source and destination, finding a routing path that achieves best performance, subject to number of constraints such as network topologies and interferences, is called optimum path [6].

Optimality principle simply states that if router J is on the optimal path from router I to router K, then the optimal path from J to K also falls along this same path. This forms a sink tree. As a result, a routing protocol is equivalent to a process of discovering different sink trees and utilizing such trees to form routing path for any source and destination.

However in reality it is much complex when multi hop wireless network such as WMN is considered. Following are the factors which make routing a more challenging task than just finding routing paths based on sink trees.

1) Inconsistent and variable network topology

a) Links between nodes can be up or down

b) Interference or fading causes link disturbances

c) Node mobility changes topology

d) Node activities, such as joining or leaving of nodes

2) It is not possible to find routing path solely based on network topology when performance goal is considered

a) Routing metric is more than just topology parameter

b) There are other routing metrics also such as delay.

c) Selection of one routing path is coupled with that of another routing path

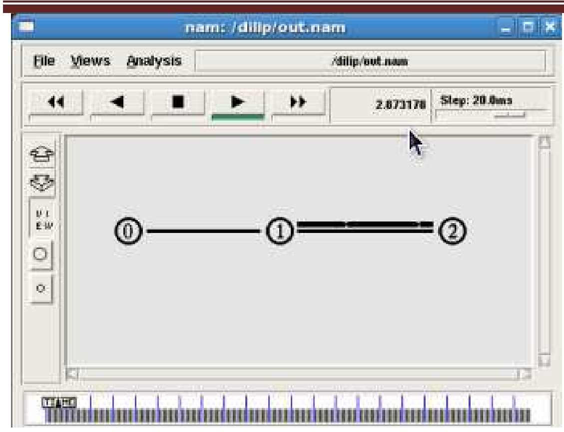
d) Determining routing path is also coupled with resource allocation mechanism including channel allocation, medium access control, power control, and so on.

e) Routing path selection has to consider load balancing with respect to traffic distribution. However traffic distribution is also result of routing. Thus load balancing and routing are closely coupled to each other. In WMN this is peculiar, and complicated as traffic load on sink impacts multiple links in the interference region [9].

Thus the challenge is how to design a distributed routing algorithm to approximate the optimization solution of a global routing algorithm.

UNFAIRNESS STUDY:

Simulation Environment: NS2



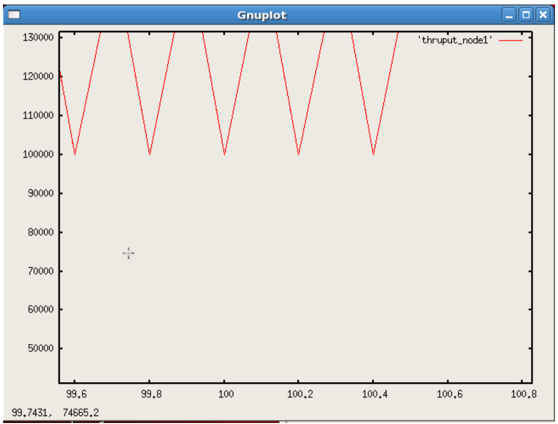
(Figure2: Experimental Setup in NS2 environment)

Simulation Parameters:

Link: Node 0 to Node 1-Duplex 3Mb 1ms

Node 1 to Node 2- Duplex 1Mb 15ms

Traffic /Connection: CBR using UDP



(Figure3: Drop In Throughput for flow 1 to 2)

Node 1 has to serve for its own traffic (local traffic) and also pass traffic from node 0 (relayed traffic). Unfairness results due to packet buffering and different waiting period as stated earlier.

BOTTLENECK NODE:

A wireless node N is said to be bottleneck node with respect to certain traffic flow i, if two conditions are satisfied [6]

1) Node N's scheduling capacity is fully consumed by all traffic flows, scheduled by it.

Let C_N denotes the total available scheduling capacity (for both transmission and reception) provided by node N.

$t(W_i) = 1$, if flow is originated or destined at node N (it means it has to be scheduled either for transmission or for reception).

$t(W_i) = 2$, if flow passes through node N.

Then for recognizing bottleneck node first condition is

$\sum t(W_i).R_i = C_N$

And the second condition is $R_i >= R_j$ where R_i and R_j is the transmission bandwidth for flow i and any other flow j respectively.

ROUTING PROTOCOLS: CATEGORIZATION AND EVALUATION

1) Criteria for Categorization:

Routing protocols can be broadly distinguished based on four criteria: Routing philosophy, network organization, location awareness and mobility management. [2]

Routing philosophy:

Routing approaches can be viewed as proactive, reactive, or hybrid. In proactive routing protocols, paths are established regardless of the willingness of a node to transmit data. In reactive (on-demand) routing protocols, routing processes are initiated upon requests. In hybrid routing protocols, some of the nodes may implement a proactive routing protocol and others a reactive routing protocol.

Network organization:

In a flat organization, all the nodes have the same role in the routing process whereas in a hierarchical organization, some nodes may have specialized functions. For example, in wireless sensor networks, cluster-based routing protocols entail the elections of super nodes (cluster heads) responsible for data gathering operations.

Location awareness:

Routing protocols may or may not use localization systems embedded in the network nodes to obtain location information.

Mobility management:

A WMN must manage the mobility of user nodes throughout the network. As they move, user devices change their point of attachment to the network, connecting to the access point with which they have the strongest signal. Mobility raises several issues, similar to those known in both wired and cellular networks. In MANETs, mobility management has been integrated into the routing process in order to cope with highly mobile nodes. In wired and cellular networks, routing and mobility management have been defined separately although complementary mechanisms.

2) Performance Metrics [2] [6]:

Depending on the network characteristics, the routing protocols can focus on optimizing one or more performance metrics. The following is a non-exhaustive list including the most commonly used metrics:

Hop Count:

Hop count is the number of hops between the source and the destination.

Expected Transmission Count (ETX):

This metric is more specific to wireless communications. It accounts for data loss due to medium access contention and environmental hazards, and considers the number of retransmissions needed to successfully transmit a packet over a link.

Expected Transmission Time (ETT):

ETT is an enhancement of ETX as it further includes the bandwidth of the link in its computation. This is of particular interest when different network technologies are used (IEEE 802.11a and IEEE 802.11b for instance) in order to favor channel diverse paths.

Energy consumption:

A node energy level can be considered as a routing metric if some nodes are energy-constrained and their involvement in the routing process can lead to path failure if they suffer from energy depletion.

Path availability/reliability:

This metric estimate the percentage of time a path is available. Node mobility effect can be captured by this metric.

ADDRESSING UNFAIRNESS:

Intuitively, fairness is the closeness of the throughput achieved by each flow to its fair share, and can be indexed as [9]

$$\text{Fairness Index} = 1 - \frac{\sum_{i=1}^{n}|xi - Avg|}{2(n-1)Avg}$$

Where Xi is the throughput achieved by flow i, Avg is average throughput of all traffic flows and n is the number of traffic flows.

In [5] it is suggested to

1) Isolate originating traffic ,
2) Apply different weight on relayed traffic
3) And Per flow queuing

Also for fair allocation of bandwidth, [6] have suggested FEBA, Fair End-to-End Bandwidth Allocation algorithm. The basic idea is to allocate bandwidth based on requests from node per flow basis. There are separate queues for each traversing flows. FEBA allocates bandwidth in round-robin manner where the bandwidth allocated, in bytes, is proportional to the number of traffic flows weighted on their priorities. Thus differentiated service is also provided by serving traffic flows on their priority [10] [11].

The weight Φ_i of any queue i is computed as [6]

$$\Phi i = \frac{\sum_{j \in A} \omega_j \cdot I_i(j)}{\sum_{j \in A} \omega_j}$$

Where A is set of all active traffic flows served by this node, j is an active flow with priority ω_j, and $I_i(j)$ is an indicator function which equals 1 if j is under service at queue i, 0 otherwise.

CONCLUSION

In this paper, the characteristics of wireless mesh networks are discussed. Also these characteristics are compared with other wireless networks and categorized existing routing protocols. It is found that new routing protocols specifically adapted for WMNs are needed. Unfairness behavior is understood by related work using NS2 simulation. Concepts like bottlenecking and fairness index are reviewed. Fair end-to-end bandwidth allocation algorithm to enforce fairness amongst nodes is also discussed with short numerical equation.

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