Cross Layer Interaction in Wireless Ad Hoc Networks

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I. The Problem

Wireless ad hoc network, which is described by [Frod] as "art of networking without a network", is a set of nodes cooperate with each other to provide some basic networking functions such as routing, data forwarding any time, any where without the help of any fixed infrastructure. Because of its high flexibility in network deployment, wireless ad hoc networks are commonly used in temporary use, or tasks such as underwater exploration or fire fighting which the it is hard for human being to complete.

An important characteristics of wireless ad hoc network is: unlike other wireless network, for example, the traditional cellular network, which only the last hop is wireless, there will be multiple wireless hops in ad hoc network. So the nodes in the network will have to contend for wireless media access each hop of the entire route. Intuitively we will expect that the throughput of ad hoc network will be less than the wired counter part give all the other conditions are same. A lot of the research work show this in both analytical result and simulations. In [Gupta] it is showed that the theoretical throughput of wireless ad hoc network is $O(\frac{1}{\sqrt{n}})$, and in reality, the throughput is about $O(\frac{1}{\sqrt{n \log n}})$, where n is the number of nodes in the network given the density is constant.

The cause of this performance degrade is the media access control protocol used in wireless ad hoc network. In order to solve the problems caused by the broadcast nature in wireless communication such as "direct interference", "self interference", different MAC layer protocol proposed different solutions, for example, ALOHA CSMA/CD, (Carrier Sensing Media Access/Collision Detection), CSMA/CA, (CSMA/Collision Avoidance), FAMA, (Floor Acquisition Media Access), IEEE 802.11. Unfortunately these solutions will cause other problems—"hidden terminal" and "exposed terminal" problems, which are the problems that one node can not send to another node because either the receiving node or the sending node itself is the the transmission range of another ongoing communication respectively.

In our preliminary work [Fang], those problems are characterized by an abstract notion, "path coupling", which is defined as the interference to transmission along one path by the simultaneous transmission along a node disjoint path through the link(s) which connects nodes from the disjoint paths respectively, the link(s) is called coupled linkage. It is also shown that the existence of "coupled linkage" among routes will degrade the performance (throughput and delay) of the network severely because the nodes may be forced to delay transmissions unnecessarily, which also agrees with the result from [Li] and [Bianchi].

This phenomenon is explained by [Li] as a performance limit of the specific MAC layer protocol, IEEE 802.11, which is commonly used in wireless ad hoc network analysis and simulation, in [Xu] it is claimed that "IEEE 802.11 is not designed to support multi-hop ad hoc arrangement". While in our work, this phenomenon is explained as the result of the cross layer interaction between the

MAC layer and routing layer and possible methods to improve the performance are proposed in the following section.

II. Possible Solutions

Unlike wired network, given any two node disjoint routes, we can easily divide traffic for optimal load balancing as the route do not interact, in wireless ad hoc networks, topologies are usually changing from time to time, and nodes contend for the media access all the time, so sometimes the transmission along one route will interfere the simultaneous transmission on another node disjoint route which is coupled to the first route by "coupled linkage(s)". Because the routing layer does not have any information on "path coupling", based on current routing algorithms it is hard for the routing layer to find the "optimal route" to provide maximum throughput as well as minimize the probability of path coupling will be caused.These characteristics of wireless ad hoc network usually lead to the poor performance in terms of throughput and network delay compared to the wired counterpart.

We are interested in two possible performance enhancing solutions. A straightforward proposition is let the MAC layer somehow inform the routing layer the information about the ongoing transmissions and the routing layer will use the information to adaptively update the metric used in routing decisions accordingly. By doing so the cross layer information is transmitted from lower to upper layer and used by the upper layer to pursue better performance.

The routing layer should used the information of the existence and the amount of traffic in the "path coupling" routes along with the possible route it will use to forward date and the degree of "path coupling" along the possible route to pick an "optimal route" for the time among several possible routes— the objective is to balance the load effectively across the routes that minimizing the coupling. In our proposition, the "degree of coupling" factor is related to the number of "coupled linkage(s)" and the position of the "coupled linkage(s)". A good way to combine these two is under study. The amount of the traffic in the "path coupling" routes is reflected by a new concept— "virtual load". "virtual load" is defined so as to compensate the time a node defer its access to the channel because of the ongoing transmission of its hidden terminals. Whether or not the "virtual load" should be exactly as the "actual load" transmitted is still not decided yet. But the idea is straightforward, the node has to defer its access either "actual load" or "virtual load" is using the link. Taken the "virtual load" into account, hopefully the problem will turn out to be a min cost man flow problem and can be solved in the existing solutions to that problem. To our knowledge, no one else has addressed the problem in this way and this is a prospective method to alleviate the problem.

An alternative solution is to replace the MAC layer protocol itself. Some proposed MAC layer protocol such as MACA-BI (Multiple Access Collision Avoidance-By Invitation), SEEDEX(Seed Exchange Media Access), DBTMA (Dual Busy Tone Multiple Access) show they will perform better under some conditions. However, this alternative solution seems less feasible from an engineering perspective due to the large installed networks based on the current standards such as IEEE 802.11. But form a theoretical standpoint it would be interesting to design and implement more optimal access schemes.

Another important issue is the scheduling. Proper scheduling should be used in order to achieve good network performance. In [Li] they claimed that "IEEE 802.11 does find a reasonably efficient schedule for interleaving two directions". However this conclusion is debateable until further analysis or simulation results show this more explicitly because in their paper it is the total throughput over both directions in stead of the throughput along each direction that is measured. Other papers [Rama] [Chlamtac] focus the scheduling itself also give some interesting result. We are not quite familiar with this respect right now and more study should be done in area.

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