Concurrent-MAC: Increasing Concurrent Transmissions in Multi-AP Wireless LANs

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ABSTRACT

This paper presents the design and performance evaluation of Concurrent-MAC, a MAC protocol for increasing concurrent transmissions in multi-AP wireless LANs. Based on SINR values between stations and APs, sets of concurrent transmitters are identified by the backhaul of APs. A station gaining access to the channel, schedules a set of its neighbors for concurrent transmissions. Neighbors chosen for concurrent transmission can start transmitting on the channel, immediately after they overhear the privilege given to them for concurrent transmission. Our simulation results show that, in dense wireless LANs, Concurrent-MAC can improve aggregate throughput significantly compared to 802.11 DCF.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Protocols

General Terms

Design, Performance

Keywords

Concurrent Transmissions, MAC-Layer, Wireless LANs

1. INTRODUCTION

Deployment of Wireless Local Area Networks has grown rapidly in the past few years. IEEE 802.11 DCF is the MAC protocol commonly used in wireless LANs. 802.11 DCF employs *Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)* scheme. In 802.11 DCF protocol, a station willing to transmit, senses the wireless channel to determine if the channel is busy or idle. If the channel is sensed busy, the station has to defer its transmission until the medium becomes idle. The main drawback of carrier sensing mechanism is that, by simply comparing received power level with a carrier sense threshold, the information regarding which station is transmitting on the channel, is lost. Some stations might be eligible for concurrent transmissions while some might not, which is directly related to the SINR values at the receiver. Concurrent transmissions are transmissions that overlap in time. The ideal MAC protocol must prevent concurrent transmissions by interfering links and allow concurrent transmissions by non-interfering links.

IEEE 802.11 protocol is designed based on a "single AP-multiple stations" architecture, in which each AP serves multiple stations and each station is associated with only one access point at a time. But in current deployments of WLANs, it is observed that, in many cases, multiple APs are present in the vicinity of each station [1]. In this paper, we refer to WLANs in which stations are covered by multiple APs as *multi-AP WLANs*. In multi-AP WLANs, due to the broadcast property of the wireless channel, packets sent by a station can be received by any of the APs present in the station's transmission range.

We believe that a new MAC protocol that efficiently utilizes the presence of multiple APs to increase network throughput should be designed for multi-AP WLANs. In this paper, we design a MAC protocol, called *Concurrent-MAC*, which exploits the presence of multiple APs and increases concurrent transmissions to improve the uplink throughput in multi-AP wireless LANs. As we have found in this work, in multi-AP WLANs, there are many instances in which nearby stations can transmit concurrently. Although the concurrent packets might collide in some of the APs, they can be captured by some other APs. Our protocol, Concurrent-MAC, exploits the presence of the infrastructure to measure the path loss between stations and APs. Based on path loss information, central controller calculates the Signal to Interference and Noise Ratio (SINR) for different sets of transmitters to exactly find out which stations can transmit concurrently. Each station is then given an accurate list of its exposed neighboring stations. Whenever a station gains access to the channel, it gives a privilege to a set of its neighboring exposed stations to transmit concurrently. In a multi-AP WLAN, two nearby stations might not be eligible for concurrent transmission if they are restricted to transmit to their associated APs. On the other hand, two nearby stations might be eligible for concurrent transmissions if their packets can be received by any AP. Our protocol, Concurrent-MAC, enables stations to transmit concurrently, if their concurrent transmissions can be captured successfully by the backhaul of APs.

MobiCom'13, September 30–October 4, Miami, FL, USA.
http://dx.doi.org/10.1145/2500423.2504582
ACM 978-1-4503-1999-7/13/09.

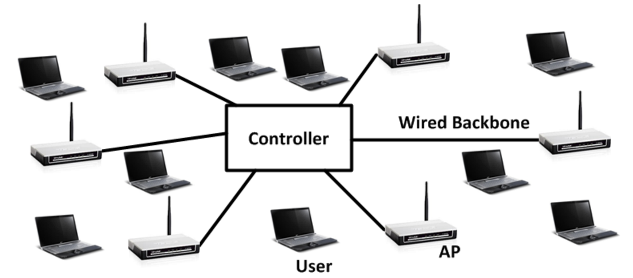

Figure 1: System architecture

2. RELATED WORK

Related work falls into two main areas:

Coordinating multiple APs in WLANs: Miu et al. [2] has designed the Multi-Radio Diversity (MRD) wireless network, which uses path diversity to improve throughput of WLANs. MRD has proposed a frame combining method which attempts to find the correct version of the transmitted frame even if it is received erroneously at all APs. Zhu et al. [3] has proposed an AP association algorithm for deciding which APs to associate with. Their proposed heuristic selects an AP to be included in the set of associated APs of a station, if the addition of that AP will increase the throughput of the station by more than a threshold.

Solving the exposed terminal problem of 802.11 DCF: [4] proposes *CMAP (Conflict Maps)*, a MAC protocol which allows concurrent transmissions by exposed terminals in wireless networks. CMAP tries to find out which stations can transmit concurrently and which can not. In CMAP, initially, all stations transmit concurrently, even if their transmissions collide. Stations then measure the loss probability to figure out which nearby stations are interfering stations and which are exposed stations, based on which, the stations build conflicting transmissions map. A station willing to transmit on the channel, considers the current transmitters and consults the conflict maps, to decide whether to transmit or defer.

3. CONCURRENT-MAC DESIGN

Figure 1 shows the multi-AP WLAN architecture we consider in this paper. Similar architecture has been proposed for multi-AP WLANs in the literate [2], [3]. APs are connected to a central component called *controller* via a wired backbone. In our protocol, Concurrent-MAC, a station is not explicitly associated with an AP and a station's packets might be received by any of the nearby APs. The APs are configured such that they receive or overhear packets transmitted by close by stations. Concurrent-MAC runs an opportunistic token passing protocol, where a token (or a privilege) is given by a transmitting station to a set of its neighbors. In this paper, we use the terms privilege and token interchangeably. Concurrent-MAC has two major components:

1. A probe phase to determine the sets of concurrent transmitters.

2. An opportunistic token passing protocol to enable concurrent transmissions.

3.1 Probe Phase

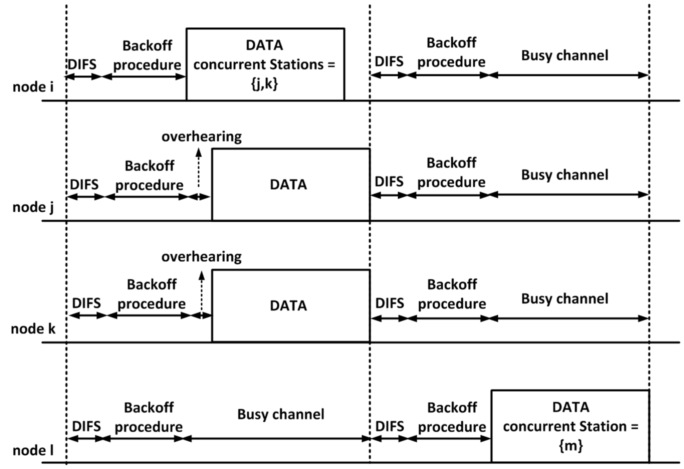

Figure 2: Access method of Concurrent-MAC protocol

In this phase, stations transmit a number of packets in a round robin manner. APs located in the reception range of each station receive the probe packets based on which the channel gain between stations and APs can be measured. APs forward the channel gain information to the controller. From this information, the controller finds the set of the stations that can transmit concurrently. Stations can transmit concurrently, if their packets can be captured by different APs. Each station is then given a list of concurrent neighbors sets, where concurrent neighbors of a station can reliably transmit concurrently with the station. Stations use concurrent stations information to schedule their neighbors for concurrent transmissions.

3.2 Enabling Concurrent Transmissions

Channel access mechanism of Concurrent-MAC is shown in Figure 2. In Concurrent-MAC, when station i transmits on the channel, it gives privilege to a set of neighboring stations, e.g. stations j and k. If privileged stations j and/or k were sensing the channel as idle before transmission of i starts, and if they overhear the privilege given to them by station i, they will start transmitting on the channel immediately. Non-privileged stations (e.g. station l in Figure 2) have to defer their transmission till when the channel becomes idle. This process of giving a privilege to a set of neighbors repeats in each successful channel access. Whenever a station transmits on the channel, a set of concurrent transmissions might start.

4. EVALUATION

We simulate Concurrent-MAC and 802.11a in ns-2 to measure and compare performance of these two MAC protocols. The network is a wireless LAN in which stations and APs are placed uniformly at random in a square area. We use a log-distance path loss model with path loss exponent of four to simulate the indoor office environment. Traffic is full buffer CBR. IEEE 802.11 RTS/CTS mechanism is turned off. Packet payload size is 1500 bytes. Each simulation lasts for 30 seconds and the presented results are averaged over 5 runs. We run the simulations for two network sizes, i.e., $15m$x$15m$ and $50m$x$50m$. We vary the number of stations

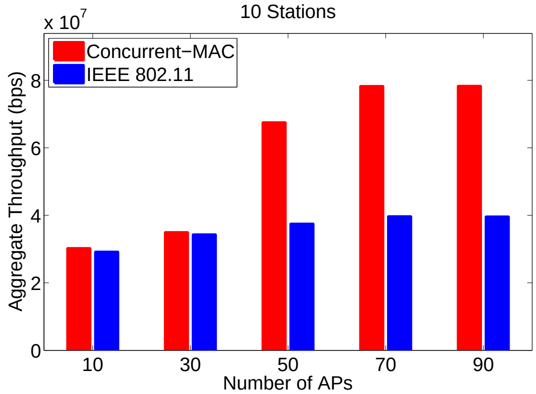

Figure 3: Single hop network (area = 15mx15m)

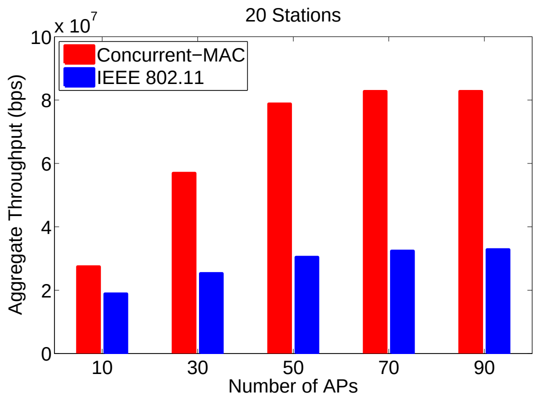

Figure 4: Single hop network (area = 15mx15m)

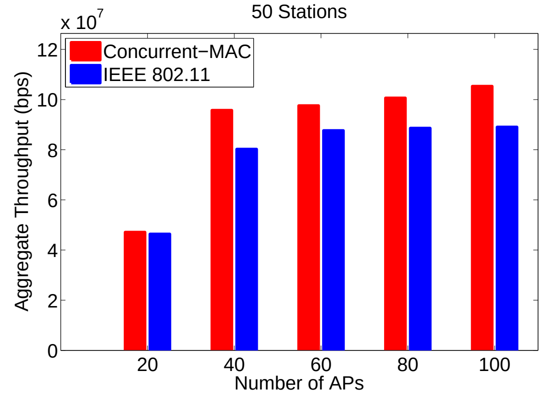

Figure 5: Multi-hop network (area = 50mx50m)

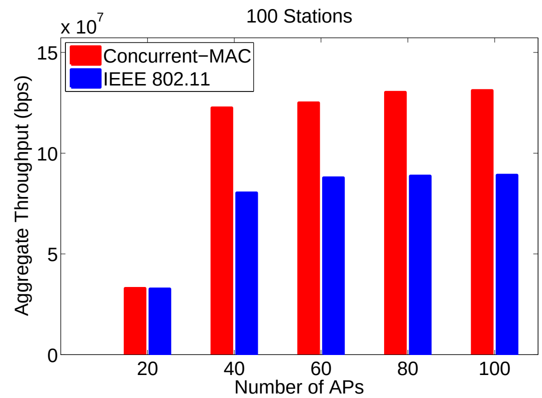

Figure 6: Multi-hop network (area = 50mx50m)

and APs in the area to investigate the effect of stations and APs density on the concurrent transmissions and network throughput.

Figures 3 and 4 plot the throughput in a single hop network of size $15m$x $15m$. With our simulation parameters, carrier sense range is $25m$. As can be seen in these figures, throughput gain obtained by Concurrent-MAC compared to IEEE 802.11 can be up to a factor of 2.5 as we increase the number of stations and APs in the area. The reason is that increasing number of stations and APs increases the number of concurrent transmissions in the network. The aggregate throughput of 802.11 DCF and Concurrent-MAC, for a multi-hop network of size $50mx50m$ is presented in Figures 5 and 6. As we observe in these figures, aggregate throughput is increased by up to 52% by exploiting the presence of many APs in the area.

5. CONCLUSION AND FUTURE WORK

In this paper, we presented the design and performance evaluation of Concurrent-MAC. Concurrent-MAC is a MAC protocol that uses an opportunistic overhearing mechanism to schedule network stations for concurrent transmissions in multi-AP WLANs. The main design goal of Concurrent-MAC is to increase aggregate throughput by allowing concurrent transmissions that can be received successfully by the backhaul of APs. Our simulation results show that Concurrent-MAC can achieve significant improvement in system throughput compared to 802.11 DCF. In future, we want to explore the effect of rate adaptation on increasing the number of concurrent transmissions in Concurrent-MAC. As we have observed in our simulations, by decreasing the rate, we might be able to increase the number of concurrent transmissions.

6. ACKNOWLEDGEMENTS

This research is supported in part by National Science Foundation award CNS 11-17539.

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