Adaptive Transmission Control for Improving Throughput Performance in Multi-Packet Reception-Enabled Wireless Networks

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Abstract

Multi-packet reception (MPR) technology makes it possible for wireless nodes to successfully receive multiple packets from simultaneous transmitters in wireless networks. As it can provide more transmission opportunities, the network throughput performance can be dramatically improved. In this paper, we propose a transmission chance adaptation strategy, which decides an appropriate level of channel access probability for each node in wireless networks. With the appropriate setting of channel access probability, the number of concurrent trans-missions would be close to MPR capability such that the throughput performance can be improved. Through extensive simulations, we show that the proposed transmission protocol outperforms the conventional IEEE 802.11 DCF mode in terms of the aggregate throughput.

Keywords: *transmission control, throughput improvement, wireless networks*

1. Introduction

In conventional wireless networks, nodes can receive only one packet at a time, while two or more concurrent transmissions cause all packet reception to fail. In general, this is known as packet collision in wireless networks. However, as the technology level of signal processing and multi-user detection (MUD) improves, it has become possible for nodes to successfully receive multiple packets from more than one transmitter at the same time.

The MPR system considered in this paper consists of a set of transmitters and one access point. This access point has MPR capability so that it is able to receive multiple packets simultaneously. We denote MPR capability by M, and imply that the receiver accurately receives up to M packets at the same time. In MPR systems, the expected number of concurrent transmissions should be close to M in order to fully utilize channel efficiency. If the number of concurrent transmissions is smaller than M , the channel is not fully utilized, leading to inefficient channel utilization. Moreover, if the number of simultaneous transmissions is larger than M, no packet can be correctly received, and as a result, the throughput performance is significantly hampered.

The problem is however, that existing medium access controls designed with-out considering MPR capability does not work well in MPR-enabled networks. For example, consider an access point (AP) with MPR capability that can receive multiple packets

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simultaneously, but if the CSMA/CA based IEEE 802.11 DCF protocol is applied, the transmitters attempt to make only one successful transmission for each channel contention. As a result, the wireless channel with MPR capability is under-utilized. Therefore, new types of MACs, which take MPR capabilities into consideration, are highly necessary for MPR-enabled WLANs [1–4].

In this paper, we first derive the saturation throughput for MPR-enabled networks. Based on throughput derivation, we propose a transmission chance adaptation scheme that adjusts the medium access probability of each node and attempts to keep the number of concurrent packet receptions close to MPR capability in order to improve overall network capacity.

2. Analytical Model and Motivation

We consider an uplink case for one-hop networks, where one AP with MPR capability is located at the center of the network, while the other transmitters are located around the AP. For simplicity, it is assumed that each node has back-logged packets in saturation condition, and the packet size is fixed to a constant value. Due to MPR capability, the AP can successfully decode all receiving packets if the number of concurrent transmissions is equal to, or less than, the value of MPR capability (*M*).

2.1. Throughput Derivation

To analyze the performance of wireless networks with MPR capability, we first derive saturation throughput performance. In this model, it is assumed that every transmitter is configured to transmit packets with the same transmission probability τ. Let M and N denote the value of MPR capability for the AP and the number of transmitters, respectively. Taking into consideration MPR capability, the conditional collision probability in the network is given by

$$p_c = 1 - \sum_{k=0}^{M-1} \binom{N-1}{k} \tau^k (1-\tau)^{N-k-1}, \tag{1}$$

where k is the number of concurrent transmissions, and τ is the transmission probability of each transmitter.

Continuing, the average length of the virtual time slot, denoted by v, is given by

$$v = \tau[(1-p_c)T_s + p_c T_c] + (1-\tau)[(1-\tau)^{N-1}\sigma + (1-(1-\tau)^{N-1})T_b], \tag{2}$$

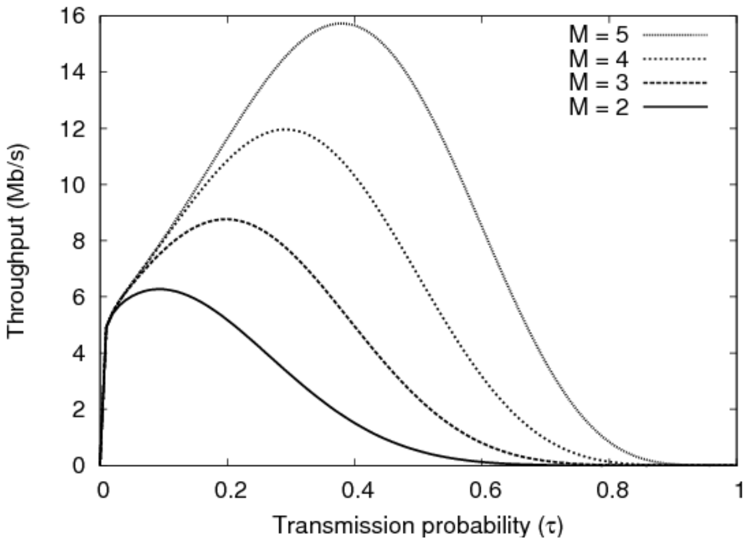
where T_s, T_c, T_b, and σ denote the durations for successful transmission, collision, a busy channel, and idle slot time, respectively.

Now, we can obtain saturation throughput for MPR-capable wireless networks, denoted by g, as follows

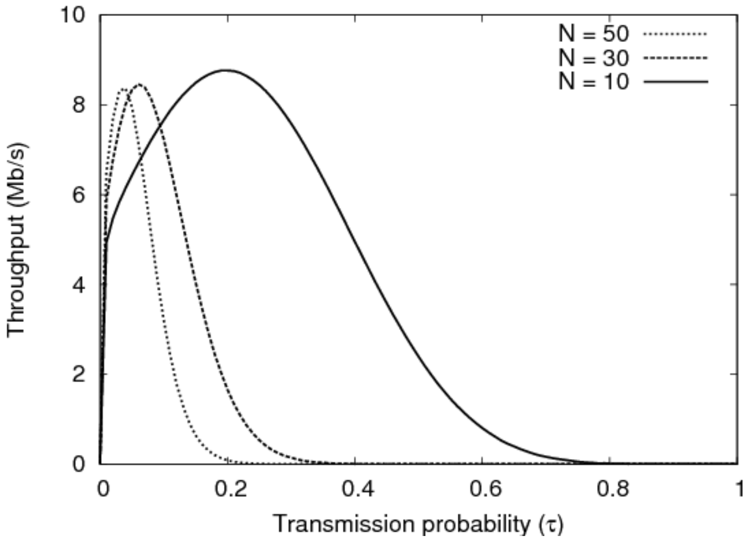
$$g = \frac{N\tau\left(\sum_{k=0}^{M-1} \binom{N-1}{k} \tau^k (1-\tau)^{N-k-1}\right) l}{v}, \tag{3}$$

where l is the average data payload size.

As depicted in the above derivation, the throughput performance of MPR-capable networks depends on the MPR capability M, the number of competing nodes N, and the transmission probability τ.



(a) A different multi-packet reception capability *M*.



(b) A different number of active users *N*.

Figure 1. Aggregate throughput performance with respect to the multi-packet reception capability and the number of active users

2.2. Motivation

As depicted in (3), the throughput performance of MPR-enabled networks depends on the MPR capability (*M*), number of competing nodes (*N*), and trans-mission probability (τ). We emphasize here that the MPR capability (*M*) and the number of competing nodes (*N*) may not be rapidly changed in a general network scenario such that these two values are assumed to be fixed values. Figure 1 shows the analytical results derived for wireless networks with MPR capability. Figure 1(a) depicts throughput performance by varying the MPR capability from 2 to 5 while the number of transmitters is fixed at 10. We observe that the throughput performance of MPR-capable networks gradually increases when the MPR capability increases.

It is observed that optimal transmission probability τ^*, which maximizes MPR channel efficiency and improves overall network capacity does indeed exist. Figure 1(b) presents the throughput performance when the number of transmitters varies from 10 to 50. In this throughput result, the maximum achievable throughput is almost the same for all values of N because MPR capability is fixed at 3. However, we also observe that optimal transmission access probability that achieves the maximum throughput is different depending on N.

Based on the above results, we conclude that a fixed transmission attempt probability for transmitters may degrade the throughput performance for MPR-capable networks. Therefore, in order to fully exploit multi-packet reception capability and improve network capacity, it is fully necessary to differentiate transmission attempt probability from M and N.

3. Adaptive Transmission Control Protocol

In order to maximize the throughput performance in wireless networks with MPR capability, the expected number of concurrent transmissions must be equal to the MPR capability (M). For example, if the expected number of concur-rent transmissions is much smaller than M , the channel with MPR capability would not be fully utilized. In contrast, if the expected number of concurrent transmissions is instantaneously larger than M, the node experiences a transmission failure, finally leading to a decrease in throughput. As shown in (3), the transmission probability (τ) is a key parameter for improving the throughput performance in MPR-enabled wireless networks. It is obvious that saturation throughput of MPR-capable networks is a function of τ when M and N are given. Therefore, the optimal value of transmission attempt probability (τ^*) that maximizes throughput performance can be easily obtained by solving

$$\frac{\partial g(\tau; M, N)}{\partial \tau} = 0. \tag{4}$$

Note that it is not easy to solve (4) for analytically, but the optimal value τ^* can be obtained numerically within the range of τ (i.e., $0 \le \tau \le 1$).

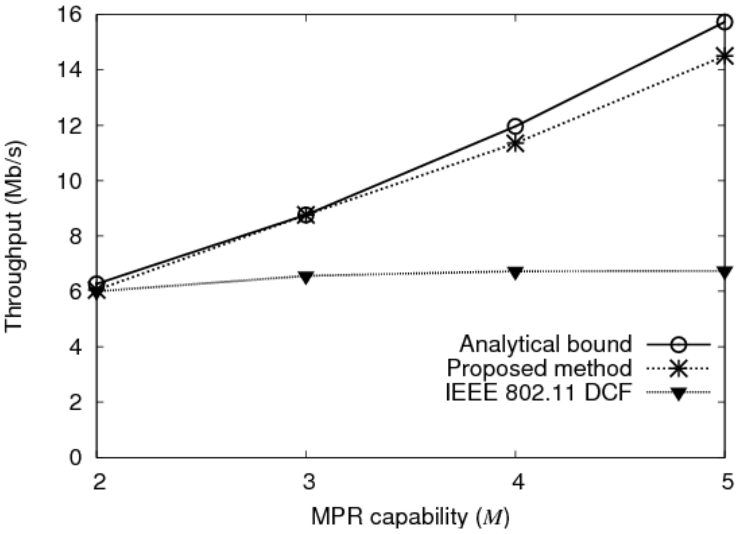
In this paper, however we mainly consider MPR-capable networks employing conventional IEEE 802.11 DCF MAC protocol. To comply with IEEE 802.11 standards, we propose a control mechanism for the contention window size (CW) rather than transmission probability (τ). In the IEEE 802.11 DCF mode, a node intending to transmit first senses the channel and defers its transmission when the channel is sensed busy. When the channel is sensed idle for a specific time interval, called distributed inter-frame space (DIFS), the sender chooses a random back-off timer, which is uniformly distributed in [0, CW − 1]. CW is initially set to its minimum value CW_{min}, and then doubles to its maximum value of CW max after each transmission collision. However, the minimum and maximum value of CW are set to a constant value in the IEEE 802.11 DCF mode so that the transmission attempt probability is always the same regardless of the number of competing nodes and MPR capability.

Note that it has been shown in previous studies [5, 6], the channel access probability of τ is given as a function of CW of IEEE 802.11 DCF protocol, i.e., $\tau = 2/(CW + 1)$ when $CW = CW_{min}$ in an average sense. Based on the above relationship between CW and transmission probability (τ), the optimal contention window size (CW^*) is given as,

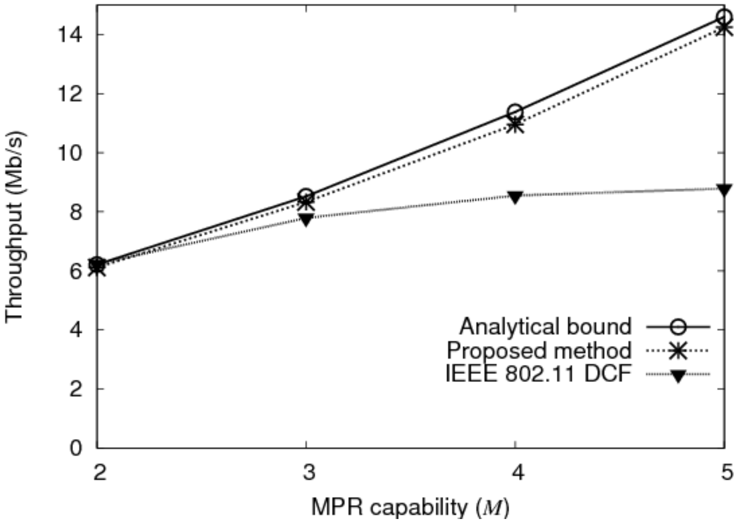
$$CW^* = \frac{2}{\tau^*} - 1. \tag{5}$$

The optimal transmission probability τ^* can be obtained by solving (4). In the proposed transmission attempt probability control scheme, every transmitter is configured to send packets with optimal contention window size computed by (5).

Once the transmitter adjusts its level for transmission attempt probability by setting a contention window size, the wireless channel utilization significantly increases. Consequently, the throughput performance also increases in MPR-capable networks.



(a) *N*=10



(b) *N*=20.

Figure 2. Throughput performance w.r.t. the MPR capability (*M*) when *N* =10

4. Simulation Results

To evaluate the performance of our proposed transmission control scheme and compare it with that of the IEEE 802.11 DCF mechanism and analytical throughput bound, we have carried out extensive simulations in a variety of network scenarios.

First we evaluate that how the MPR capability M affects network performance. We then show how a frame size affects network performance. In addition, we compare the performance of our proposed scheme with the analytical throughput bound and IEEE 802.11 DCF.

4.1. Aggregate Throughput Performance w.r.t. *M*.

In this set of simulation experiments, we show that MPR capability *M* affects the aggregate throughput performance in MPR-capable networks, where the number of nodes is 10 and 20, respectively. As stated above, *M* can significantly improve the throughput performance with an appropriate setting for transmission attempt opportunity. In Figure 2, the aggregate throughput obtained by the IEEE 802.11 DCF mode approximates even though MPR capability (*M*) increases. The reason is that each transmitter sends packets with the same transmission attempt probability under IEEE 802.11 DCF so that the channel fails to be fully utilized in MPR-capable networks. However, the throughput obtained by the proposed method almost achieves the analytical maximum bound for the throughput performance. The implication is that the channels in networks with MPR capability are more efficiently utilized by adopting the transmission opportunity.

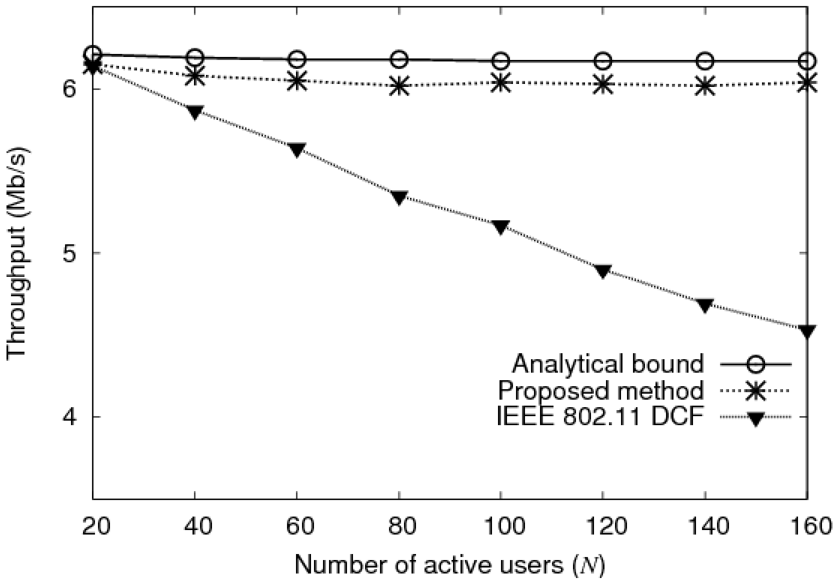


Figure 3. Throughput performance w.r.t. the number of users (*N*)

4.2. Aggregate Throughput Performance w.r.t. *N*

We carry out simulations to show the throughput performance with respect to the number of users N. In this set of simulations, the MPR capability is set to a fixed value of 2. As shown in Figure 3, the throughput performance gradually decreases as *N* increases under the IEEE 802.11 DCF mode. With this fixed CW value of IEEE 802.11 DCF, each node transmits packets with the same transmission probability regardless of *M* and *N* in MPR-capable networks.

Consequently, the channel utilization significantly decreases due to a large number of collisions as the number of transmitters increases. In contrast to IEEE 802.11 DCF, the throughput performance does not degrade in our proposed transmission opportunity control scheme as the number of transmitters increases.

Under the proposed scheme, every transmitter adjusts its CW_{min} value to fully exploit MPR capability by considering *M* and *N*, resulting in significant throughput improvement. We also observe that the throughput of transmission opportunity control scheme is quite close to the analytical bound derived for wireless networks with MPR capability. It implies that the channel is efficiently used under our proposed scheme.

4.3. Aggregate Throughput Performance w.r.t. Packet Size

We also carry out simulations by varying the packet size from 0 to 8000 bits. The packet size is one of the most important parameters significantly affecting network throughput. Figure 3 gives the aggregate throughput versus the packet size when the number of active transmitters (*N*) is set at 10. In the simulations, the MPR capability and number of transmitters are set to a constant value to verify the effect of the packet size. Figure 4 shows a similar performance trend. As we increase the packet size from 0 to 8000 bits, the aggregate throughput gradually increases. Under the proposed transmission opportunity control scheme, the channel is fully utilized by adjusting CW value appropriately. Therefore, we can achieve the network throughput to analytical throughput bound.

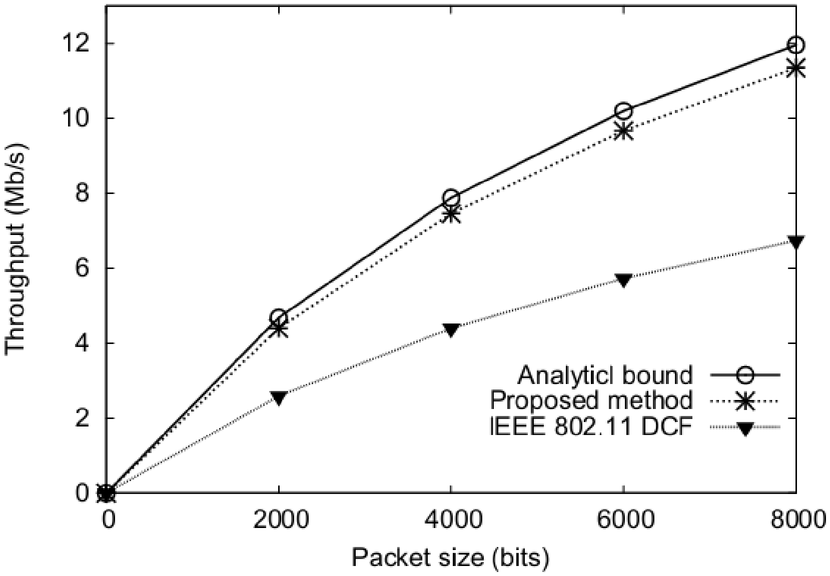


Figure 4. Throughput performance w.r.t. packet size (*l*)

5. Conclusions

We presented issues for improving the network throughput performance in wireless networks with MPR capability. We investigated the throughput performance in wireless networks with MPR capability. We showed that optimal transmission probability that maximizes network throughput performance does indeed exist. Based on observations, we proposed a transmission opportunity control scheme that adjusts transmission attempt probability in order to improve channel utilization and aggregate throughput within MPR-enabled networks. The simulation results showed that this proposed scheme significantly increases throughput performance, which closely resembles the analytical maximum bound derived for MPR-enabled networks.

References

[1] Y. J. Zhang, "Multi-round contention in wireless LANs with multipacket reception", IEEE Transactions on Wireless Communications, vol. 9, no. 4, **(2010)**, pp. 1503-1513.

[2] P. X. Zheng, Y. J. Zhang and S. C. Liew, "Multipacket reception in wireless local area networks", IEEE International Conference on Communications (ICC), **(2006)**.

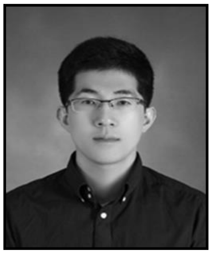
[3] H. Chen, F. Yu, H. Chan and V. Leung, "A novel multiple access scheme over multi-packet reception channels for wireless multimedia networks", IEEE Transactions on Wireless Communications, vol. 6, no. 4, **(2007)**, pp. 1501-1511.

[4] J.-S. Liu and C.-H. R. Lin, "Distributed splitting-tree-based medium access control pro-tocol for multiaccess wireless networks with multipacket reception", IET Communications, vol. 2, no. 9, **(2008)**, pp. 1170–1176.

[5] G. Bianchi, "Performance analysis of the IEEE 802.11 distributed coordination function", IEEE Journal on Selected Areas in Communications, vol. 18, **(2000)**, pp. 535-547.

[6] F. Cali, M. Conti and E. Gregori, "Dynamic tuning of the IEEE 802.11 protocol to achieve a theoretical throughput limit", IEEE/ACM Transactions on Networking, vol. 8, **(2000)**.

Authors



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