A Survey on Multi-Packet Reception with Random Access in Wireless Networks

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ABSTRACT

This survey provides a comprehensive review of existing carrier sensing enhancements for IEEE 802.11 wireless networks. Medium Access Control (MAC) Layer plays a significant role in Wireless Local Area Network (WLAN). The original physical carrier sensing mechanism, used by wireless stations to gain access to the medium is limited. It faces lot of challenges in terms of packet loss, fairness, collisions, reception and vulnerable to near-far problem. Multi-Packet Reception (MPR) technology addresses the above problem and provides the capability for a wireless receiver to parallely decode multiple packets from concurrent transmissions. New research advances are leading to increase in the reception capability of a single centrally receiving node called Access Point (AP) in WLAN. This article presents an in-depth survey of the existing literature in this area, detailing the various approaches and their efficacy in addressing the near-far problem and consequently increasing performance. It offers a comparison of the techniques, by evaluating the models, limitations, assumptions, and performance gains. The benefits of MPR technology in terms of throughput gain and reduction in packet collision and its various technologies that enable MPR at the datalink layer of a wireless network stack are highlighted. Finally, this article bestows an intuition to achieve sustained throughput and to eliminate near-far problem.

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1 INTRODUCTION

Wireless local area network (WLAN) links to several devices using wireless distribution technique. In wireless networks we have two packet reception methodologies viz., Single and Multipacket reception.

In a Multi-Packet Reception (MPR) technology, one node receives multiple packets concurrently from multiple transmitters and ensures high capacity and throughput. A network node capable of correctly receiving signals from multiple transmitters is called as an MPR Node. MPR finds its application in an uplink scenario of a random access wireless network, in which multiple nodes transmit packets simultaneously to the AP.

2 NEED FOR MPR

The conventional collision channel model allows only a single user to transmit a packet to the receiver successfully and all other active users are kept idle to avoid collisions. This approach under-utilizes the capacity of a wireless network. However, MPR technology helps in improving throughput especially in high traffic conditions.

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MPR is realized using sophisticated spread spectrum, space-time coding, signal processing techniques and antenna arrays for channel access and enabling the receiver to be able to decode multiple concurrent signals from different transmitters. The lack of synchronization among physically separated nodes in distributed networks introduces significant challenges towards adopting MPR technology in the physical layer of the 802.11 Wireless LAN protocol stack and in the data link layer specifically MAC layer for systems using MPR.

3 MPR CHANNEL MODEL

The two widely used MPR Channel Models are,

3.1. **Generalized MPR Channel**: With generalized MPR channel model [1], a node will be able to receive j out of I transmissions with some non-zero probability. When there are simultaneous transmissions, the conditional probabilities describe the reception instead of deterministic failure. Also, the probability of successful reception depends only on i and j as per equation (1),

For, $i \geq 1, 0 \leq j \leq i$

$$P_{i,j} = Pr \text{ -----------------------------} (1)$$

{j packets are received | i packets are transmitted}

A generalized MPR channel is characterized by the probabilities for all values of i and j. These values can be summarized in a new multi-packet reception model and is defined by the MPR reception matrix of the channel as per equation (2),

$$P_{i,j} = \begin{bmatrix} p1.0 & p1.1 & - \\ p2.0 & p2.1 & p2.2 \\ p3.0 & p3.1 & p3.2 \\ p4.0 & p4.1 & p4.2 \\ pn.1 & pn.2 & ----- pn.n \end{bmatrix} \text{------------ (2)}$$

Where, $P_{i,j}$ is the conditional probability that, given I users transmit, and j out of i transmissions are successful.

3.2. k - MPR: In a k - MPR channel, a node will be able to receive all the packets successfully without any loss if the number of transmitted packets is not greater than k. Equation (3) shows that with the number of transmissions going above k, packet collision occurs and the nodes will not be able to receive any of the packets which will lead to complete packet loss. Let us assume that if k denotes the number of concurrent transmissions in a collision domain,

$$P_r = \begin{cases} 1 & if \quad K \leq n \\ 0 & if \quad K > n \end{cases} \text{------------------ (3)}$$

4. MPR IMPLEMENTATION TECHNIQUES

Various MPR techniques are summarized in this section. Many of these MPR techniques are used only for mobile communication systems like cellular networks but only a few of the techniques are used for distributed wireless random access networks due to its random channel access behavior. Based on the currently available research work on MPR technologies, MPR implementation techniques can be grouped under three main categories.

4.1. MPR enabled Transmitter

This method enables MPR techniques at the wireless transmitting node. Code Division multiple access (CDMA), Single-carrier frequency-division multiple access (SC-FDMA) and Orthogonal frequency division multiple access (OFDMA) techniques come under this category. The first class of techniques that enable MPR require a significant effort by the transmitter. Examples such as CDMA and OFDMA fall into this class. CDMA allows multiple users to be multiplexed over the same wireless channel by employing a coding scheme where each transmitter is assigned a unique code. The baseband signal is multiplexed with a spreading code running at a much higher rate. The spreading code is a pseudorandom code, and all codes used for one channel are orthogonal. Therefore, on the receiver side, an unwanted signal will be eliminated by the cross-correlation decode, and only the relevant signals are conserved. This technique allows the receiver to decode multiple data streams with the different codes that are known as a priori. The ability to decode multiple data packets depend on the selection of code. For example, the orthogonality is the key that allows the receiver to decode the set of simultaneous arrived signals, and this is done on the transmitter side.

4.2. MPR enabled Trans-Receiver

This method enables MPR by enabling both the wireless transmitting and receiving nodes. Multiple-Input Multiple-Output (MIMO), Signal Separation and Polynomial Phase Sequence techniques come under this category. Beamforming, Spatial Diversity (SD), Space-Time Coding (STC) and Spatial Multiplexing (SM) are some of the well-known MIMO techniques. Known Modulus Algorithm (KMA), Algebraic KMA, Constant Modulus Algorithm (CMA) and Multiple Modulus Algorithm (MMA) are signal separation techniques. In this class of techniques, to enable MPR, transmitters and receivers should cooperate on some operations. Multiantenna MIMO system [4] can achieve MPR by exploiting the spatial diversity of the transmissions.
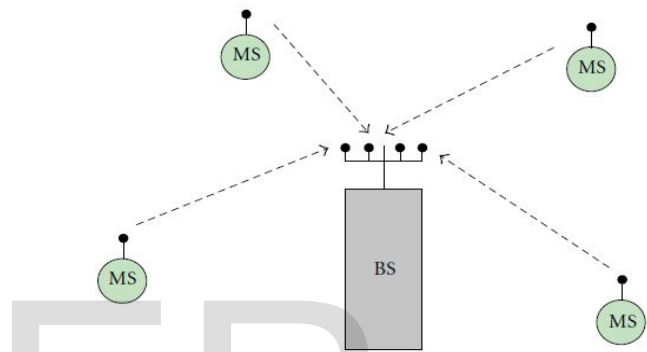

Figure 1: The BS is MPR in a MIMO system with multiple antennas.

In such a system, each antenna corresponds to a different channel characteristic $H(t)$. Channel estimators equally distinguish the packets sent by each antenna. In case of a cellular or AP-based wireless network, the communication between Mobile Station (MS) and Base Station (BS) is based on the MPR capability of the BS (Figure 1). The realization of MPR in a multi-antenna MIMO system requires both transmitters and receivers to implement specific functionalities. That is how it differs from pure transmitter-based techniques.

4.3. MPR ENABLED RECEIVER

When compared to the previous two classes, this class of solutions comes closer to the ideal of MPR, to shift the responsibility from transmitters to receivers. . The Match Filter (MF) and Multiuser Detection (MUD) techniques come under this category. The Match Filter (MF) approach is widely used for single user detection. Even though it is not optimal when multiple users are present, still a receiver can use a bank of Match Filters [9] to decode packets coded with spreading codes that need not be orthogonal. Techniques used to separate signals for Multiuser Detection (MUD) are more applicable for MPR [2, 10]. It is a way to alleviate Multiple Access Interference (MAI) during

the simultaneous transmissions on the same channel. It enables MPR at the wireless receiving node. It makes the receiver responsible for implementing MPR technology and has a more realistic approach

5. MPR LITERATURE SURVEY

An attempt has been made to perform a clear critique of MPR techniques, channel model and analysis of performance parameters for WLAN. The Generalized Channel Model for MPR [1] was first introduced for Slotted ALOHA with no CSMA and analysed one-hop throughput and stability [1], [4] properties. This channel model has been widely accepted and used in many of the research works [1], [4-9], [11-13], [15-16]. K-MPR Model has been cited in few of the research works [14]. A lot of research has been carried out in analysing various MPR techniques and its associated performance parameters. The probability of error parameter for a multiple-access channel shared by multiple users transmitting asynchronously has been analysed using Optimal Maximum Likelihood Sequence Estimation (MLSE) MUD technique [3]. This MPR technique demonstrates excellent performance but it is too complex. The bit-error-rate performance of a suboptimal linear de-correlated detector [5] has been analysed for demodulation of asynchronous CDMA signals. It shows that the bit-error-rate is independent of the energy of the interfering users and shows similar near-far resistance as the optimal MUD. The de-correlated detector is less complex than the optimal MLSE detector, does not require information about the received energies and shows similar performance.

The signal processing techniques implemented at the physical layer of a MPR receiver impact the MAC layer since it needs to schedule and handle simultaneous packet reception and avoid collisions. MPR is not supported by the conventional DCF MAC protocol. Several research works involved in designing the MAC layer to support MPR and maximize network throughput and capacity. Cross-Layer interactions between physical and MAC layers have been proposed to support multi-access channel at the MAC layer using temporal, spatial and spectral diversities of the signal at the physical layer. Local and End-to-End throughput parameters for MIMO, CMA and CDMA based systems along with MAC protocols are discussed by author [6]. A new MPR system with modified version of DCF MAC protocol and multiple antennas at the PHY layer of AP for 802.11 WLAN [7] greatly improves the throughput. It shows that the throughput increases linearly with increase in the number of antennas and ensures scalability of MPR system. It assumes synchronous packet transmission scenario and modifies the control frames format of CTS and ACK frames by

copying client stations addresses. It achieves throughput of 25 and 50 Mbps for 50 nodes with MPR capability of 2 and 4. The works of [5,10] proposed that the multi-antenna MIMO systems can achieve MPR by making use of spatial diversity of the transmissions technique by placing multiple antennas as far as possible. The transmitted signals experience independent fading leading to a maximum diversity gain. It uses RTS/CTS based MAC protocol to achieve simultaneous packet reception and avoid collisions.

TABLE 1 WLAN WITH MPR

Protocol	MPR Realization	MPR Adaptation	Performance Results
Zheng's[8]	Multiple antennas on AP	Modified CTS	Maximum throughput Scale with k (K-MPR)
Huang's[9]	MIMO with multiple Antennas	Allocation Scheme	5.2 packets/ms (With MIMO) 3.1 packets /ms (SPR)
DFT[10] IFT[10]	Spreading Centralized Control by AP	Contention resolution	77.3 % of theoretical throughput 68.7%

Many of the PHY layer parameters like channel state information, space time coded beamforming, multiuser detection, and subcarrier frequency achieves simultaneous packet reception and avoid collisions. And power allocation have been considered. The above table describes the WLAN with MPR in four different scenarios.

6 MAC PROTOCOLS FOR MPR TECHNOLOGY

A MAC protocol for multi-packet reception technology is designed and implemented based on the underlying physical layer technology which is known as a Cross Layer (PHY- MAC) protocol. The de facto standard for WLAN medium access is the IEEE 802.11 DCF MAC. DCF MAC protocol is known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). In 802.11 DCF, only one station is allowed to transmit at a particular point of time. In the early 2000s, a random access MAC protocol Receiver Controlled Transmission (RCT) [7] was proposed for multi-hop ad hoc networks with MPR nodes. The hybrid scheduling determines receiver nodes & then transmitters for each receiving node. The throughput performance of RCT was 2.5 packets / slot (SPR) and 4.7 packets / slot (MPR).

Multiqueue Service Room (MQSR) [9] was the first MAC protocol designed specifically for the networks with MPR capability where it gives superior throughput and performance. But, the greatest disadvantage of this protocol is that it requires High Computational cost due to frequent updates. It proposes a new MAC protocol for heterogeneous networks with finite population. MQSR controls the size of the access set dynamically based on the channel MPR capability and the traffic load so that the expected number of successfully transmitted packets is maximized under a set of delay constraints. With transmission probability, P = 1 and 0.5, it achieves maximum SPR and 2-MPR throughput of 1.05 and 1.95 respectively.

A new cross-layer XL-CSMA Protocol [13] was proposed which used channel sensing technique for the first time. Its disadvantages were that it neither modeled ACKs nor time-based backoff mechanism. It shows moderate throughput improvement across the MPR channels. It achieves normalized throughput of 5.1 (XL-CSMA) and 4.5 (CSMA) with channel capacity of 7 for 10 nodes scenario with packet length of 100. This protocol modifies IEEE 802.11 RTS/CTS handshaking procedure but has overheads due to RTS/CTS. The throughput is improved as number of nodes increases. The MPR capability value increases as the network size increases. It achieves throughput of 5.25 and 7.75 Mbps for 10 and 100 nodes respectively with average transmission probability of 0.5, MPR capability of 4 and average SNR value of 25 dB at receiver

A Generic Distributed Probabilistic Protocol (GDP) [14] which addresses near-far problem in a wireless network was proposed. It modifies contention window. The node decreases its transmission probability following success and increases it following failure. It improves throughput and fairness. Cooperative Multi-Group Priority Queuing (CMGPQ) MAC Protocol [15] was proposed which exploits cooperative diversity design for MPR MAC protocol for improving system throughput. It uses Client-Server model with one part in the base station and the other in wireless nodes. The drawback of this protocol is it neither modeled ACKs nor timer-based backoff mechanism. The following table describes how the MAC with MPR works in four different protocols.

7 PROPOSED INTUITION

By using MPR the system will obtain a sustained - throughput irrespective of network environment since multiple packets can be manipulated simultaneously. We propose an intuition that provides sustained throughput, minimal packet loss and eliminates near-far problem. We can adapt MPR technique like scheduling and reception feedback [8]. This paves way to have optimal throughput even in various network conditions. Incorporating switching between two transmission probabilities eliminates near-far

problem [10].

TABLE 2 MAC WITH MPR

Protocol	MPR Adaptation	Performance Results
RCT[8]	Scheduling, reception feedback	4.7 Packets /slot (MPR) 2.5 packet/slot(SPR)
MQSR[9]	Estimates the states of user	Max Throughput P=.5 (MPR) Max Throughput P=1(SPR)
GDP[10]	Switching between two transmission probabilities	Improved overall throughput fairness
CMGPQ[11]	Cooperative multigroup priority queuing	30 % improvement under light load (P<0.6)

8 CONCLUSION

In current context, MPR technology has become increasingly popular in Wireless Local Area Networks to meet the growing demands of higher data rates, lesser probability of collision, lesser packet delay, higher capacity and maximum stability. This paper lists out consistent progressive research work done in the past in relation to MPR and its impact on the PHY and MAC layer of the WLAN protocol stack. With MPR, a receiver node can receive multiple packets simultaneously and thus improves the capacity and throughput of the network. We introduce an intuition which eradicates near-far problem thereby enhancing QoS.

REFERENCES

[1] S. Ghez, S. Verdu, and S. C. Schwartz, "Stability properties of slotted ALOHA with Multipacket reception capability," IEEE Trans. Automat. Contr., vol. 33, pp. 640–649, July 1988.

[2] R. Nelson and L. Kleinrock, "The spatial capacity of a Slotted ALOHA multihop packet radio network with capture," IEEE Transactions on Communications, vol. 32, no. 6, pp. 684–694, 1984.

[3] S. Verdu, "Minimum probability of error for asynchronous Gaussian multiple access channels," IEEE Transactions on Information Theory, vol. 32, no. 1, pp. 85–96, 1986.

[4] S. Ghez, S. Verdu, and S. C. Schwartz, "Optimal decentralized control in the random-access Multipacket channel," IEEE Trans. Automat. Contr., vol. 34, pp. 1153–1163, Nov. 1989.

[5] R. Lupas and S. Verdu, "Near-far resistance of multiuser detectors in asynchronous channels," IEEE

Transactions on Communications, vol.38, no. 4, pp. 496–508, 1990.

[6] L. Tong, Q. Zhao, and G. Mergen, "Multipacket reception in random access wireless networks: from signal processing to opti mal medium access control," IEEE Commun. Mag., vol. 39, pp. 108–112, Nov.2001.

[7] A. J. Van der Veen and L. Tong, "Packet separation in wireless ad-hoc networks by know modulus algorithms," in Proceedings of the IEEE International Conference on Acoustic, Speech, and Signal Processing (ICASSP '02), vol. 3, pp. 2149–2152, Orlando, Fla, USA, May 2002.

[8] P. X. Zheng, Y. J. Zhang, and S. C. Liew, "Multipacket reception in   wireless local area networks," in *Proceedings of the IEEE International Conference on Communications*, vol. 8, pp. 3670– 3675, Istanbul, Turkey, June 2006.

[9] W. Huang, K. Letaief, and Y. Zhang, "Cross-layer multipacket reception based medium access control and resource allocation for space-time coded MIMO/OFDM," *IEEE Transactionon Wireless Communications*, vol. 7, pp. 3372–3384, 2008.

[10] J. B. Seo and V. C. M. Leung, "Design and analysis of cross-layer contention resolution algorithms for multi-packet reception slotted ALOHA systems," in *Proceedings of the 18th International Conference on Computer Communications and Networks (ICCCN '09)*, pp. 1–6, August

[11] L. Tong, V. Naware, and P.   Venkitasubramaniam, "Signal processing in random access," IEEE Signal Process. Mag., vol. 21, pp. 29–39, Sept. 2004.

[12] Q. Zhao and L. Tong, "A dynamic queue protocol for multi-access wireless networks with multipacket reception," IEEE Trans. Wireless Commun., vol. 3, pp. 2221–2231, June 2004.

[13] D. S. Chan and T. Berger, "Performance and cross-layer design of CSMA for wireless networks with multi-packet reception," in Proc. 2004 IEEE Asilomar Conf. Signals, Syst., Computer., vol. 2, pp. 1917– 1921.

[14] M. Coupechoux, T. Lestable, C. Bonnet, and V. Kumar, "Throughput of the multi-hop slotted aloha with multi-packet reception," Wireless On-Demand Network Systems, vol. 2928, pp. 239–243, 2004.

[15] V. Naware, G. Mergen, and L. Tong, "Stability and delay of finite user slotted ALOHA with multipacket reception," IEEE Trans. Inf. Theory, vol. 51, pp. 2636–2656, July 2005.

[16] P. X. Zheng, Y. J. Zhang, and S. C. Liew, "Multipacket reception in wireless local area networks," in Proc. IEEE International Conference on Communications, vol. 8, pp. 3670–3675, June 2006.

[17] J. J. Garcia-Luna-Aceves, H. R. Sadjadpour, and Z. Wang, "Challenges: towards truly scalable ad hoc networks," in Proceedings of the 13th Annual ACM Int'l Conference on Mobile Computing and Networking (MobiCom), pp. 207–214, Montreal, Canada, September 2007.

[18] J. J. Garcia-Luna-Aceves, H. R. Sadjadpour, and Z. Wang, "Extending the capacity of ad hoc networks beyond network coding," in Proceedings of the Int'l Conference on Wireless Communications and Mobile Computing (IWCMC '07), pp. 91–96, Honolulu, Hawaii,   USA,   August   2007.