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ORIGINAL RESEARCH

Tackling control channel saturation for load balancing in multi-channel mobile ad hoc networks

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Abstract Multiple wireless channels in Mobile Ad hoc Networks (MANET) promises to improve Quality of Service (QoS) and their well coordinated usage can result in significant operational improvements. Traditional methods implementing multi-channels in MANET uses control channel based approach for synchronization and coordination among multiple channels. Control channel is a separate and dedicated channel reserved for performing channel negotiations and other control operations. In multi-channel MANET, conventionally all mobile devices have to resort to the control channel for channel reservation during a well defined beacon interval. This approach requires tight synchronization and works well when magnitude of traffic and node density is moderate. With the rise in traffic and node density, the control channel becomes saturated and network operation is compromised. The paper proposes Parallel Rendezvous Multi-Channel MAC (PRMMAC) protocol based on the concept of multi-channel communications and results reflects that it resolves the basic saturation of the control channel and ensures a balanced load among multiple channels catering to data communication needs. Key findings of the proposed system has been observed in terms of throughput, frame delivery ratio and delay under varied networks and channel configurations and significant performance improvement in terms of throughout delay and Frame Delivery Ratio (FDR) has been observed in comparison to other protocols of its category.

Keywords MANET · QoS · Medium access control · Multi-channels · Spectrum utilization

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1 Introduction

Use of Multi-channels is prevalent in wired communication networks and exhibits great improvement over single channel based networks. In the past two decades the use of multi-channels has been used in wireless networks also and is gaining constant popularity. But, there has been little work done concerning the use of multi-channels in mobile ad hoc networks. In the context of mobile ad hoc networks no commercial product is available supporting multi-channels and there exists a huge scope of improvement and research in this area.

Wireless networks use Carrier Sense Multiple Access (CSMA) method for medium access [1, 2]. In CSMA environment, a single channel is shared by all the participating nodes (within carrier sensing range) and due to this sharing the communication is highly contentious and frame collision rate is also high. This sharing severely affects performance parameters like throughput and channel utilization [3]. One obvious limitation of this approach is that only a single communication can be active at a give point of time and other nodes must defer their communication until the current communication is over [4, 5]. In order to circumvent all these issues multiple channels can be used. Number of protocols have been developed [6–8] which utilizes the capacities and advantages of wireless multiple channels. Multiple transmissions are permitted simultaneously along with the capability for channel switching. The multiple channels offered are non-overlapping in nature and hence can support parallel simultaneous transmission abilities [9]. These increased channels provide increased availability and increased transmission rates than that of single channel networks. The participating nodes should be capable of using these increased channels to exploit the benefit offered [10]. Further, the nodes should ensure the use of non overlapping channels so as to minimize interference. Various versions of IEEE standards, specifically 802.11 offers varied number of communication channels like 802.11b offers 3 and 802.11b offers 12 channels [11, 12, 21].

For coordination among channels number of methods are used and most commonly used approach is the control channel based approach [35, 37]. In control channel approach, a dedicated channel is reserved for synchronization and control data transmission [13, 14]. Figure 1 shows the schematic diagram of control channel approach depicting data channels (DCH) and Control Channels (CCH). The beacon and data transmission interval are the major time slots. The mobile devices switch to the control channel during the beacon interval for the negotiations of channel utility and other considerations [15]. Figure 2 presents this timing sequence and major timing intervals. In most implementations, the control channel is not used for data transmission purposes and if used it entails tight timing requirements and other overheads [33, 34].

Since CCH is used by all the participating nodes [16, 17], with the rise in density, it may become saturated and network operation can be compromised and problems like starvation may occur. This paper investigates and proposes a method which removes the problem of control channels saturation and other concerning issues. The second issue that is of utmost importance is the load distribution and load balancing among multiple channels [18, 19]. A novel method to balance the load among multiple channels has also been proposed. The proposed load balancing framework produces significant improvements in network Quality of Service (QoS) parameters. The proposed protocol incorporates these features and is named Parallel Rendezvous Multi-channel MAC protocol (PRMMAC).

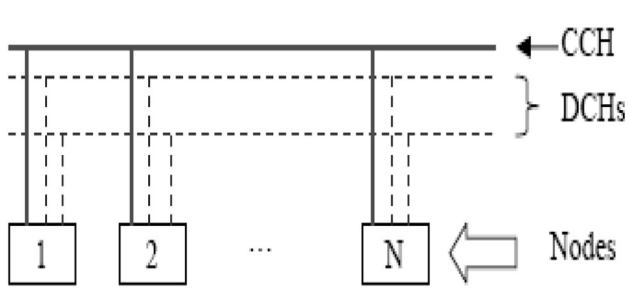


Fig. 1 Schematic diagram of control channel approach

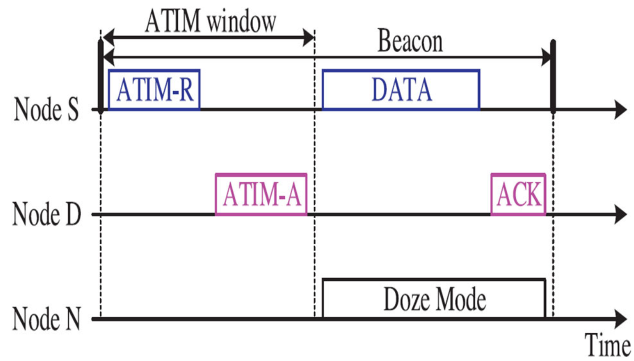


Fig. 2 Channel reservation process using control channel approach

2 Related work

As the work presented investigates the use of multi-channels, use of spread spectrum and load balancing among channels, so in the following paragraphs related work has been discussed. Plenty of Multi-Channel protocols are based on concept of control channel based approach which serves as a point of synchronization. Other set of protocols which do not use the CCH approach [22, 23] works under the assumption of single transceiver or uses the concept of channel hopping. [20] proposed a method based on the concept of CSMA wherein N number of nodes compete for M number of channels. A random channel is selected from the list of available channels through device transmitters. [23] proposed a protocol based on the concept of multi-frequency MAC and is developed for Wireless Sensor Networks (WSN). For sending, receiving and sensing, multiple frequencies are exploited and handshaking method is avoided.

Some MAC communication protocols use multiple transceiver and one such approach in discussed in [24]. This method incorporates the use of multiple transceivers and power control to select a channel. The sender-receiver pair keep monitoring all the channels and the channel with the least signal power is chosen. In this category, another method presented in [25] advocates equality of transceivers per node and channels. This protocol uses concept of soft channel reservation, i.e., the channel which was last successful is chosen. In [26] a power saving multi-channel protocol for Wireless local area network has been proposed. In this protocol, the time is divided into three phases where first phase calculates number of active links, in second phase channel negotiation is done and third phase is reserved for transmission.

Many protocols have been developed on the concept of control channel and are widely in use [42–44]. Number of these implementation assume the presence of single transceiver whereas other assume M number of transceivers. One such asynchronous protocol based on multi-channel concept [27], advocates that for making selection decisions, each mobile device consults its own channel table. [28] discusses similar protocol in which a beacon signal is used for channel selection and coordination. All the nodes listen to control channel in this beacon interval to make channel reservations. One protocol which uses multiple transceiver proposed in [14] discusses equality of transceivers and channels for each node. [29, 30] use dynamic channel assignment and each node is equipped with two half duplex transceivers.

Also, spread spectrum techniques are used to perform multi-channel selection and data transmission. In [31] one such protocol is discussed wherein codes are assigned to channels and nodes. During handshaking, the orthogonal codes are looked into and channel are selected based on the code but fails to tackle the near far problem. Hop reservation multiple access (HRAM) presented in [32] uses handshaking to perform channel selection. In this protocol, all mobile devices hear common hopping sequence and for initiating communication, the nodes try to initiate handshake on the present node. The same channel is selected for data transfer in case of handshake success else next node is tried to find a suitable channel. Code Division Multiple Access (CDMA) is another major method for multi-channel communication that uses direct sequence spread spectrum.

3 Proposed model

The proposed Parallel Rendezvous Multi-Channel MAC protocol (PRMMAC) is based on the concept of multi-channel communications and if these multiple channels are used properly then it can enormously impact the system performance and very high transmissions rates can be achieved. Figure 3 presents the schematic diagram of multi-channel communications in the proposed system. Herein, it can be seen that a single mobile device or host can simultaneously communicate with multiple hosts on different channels. In this setup, each node uses multiple transceivers to enable simultaneous communications. Figure 4 shows Network Interface Card (NIC) installed in each node with multiple transceivers embedded into it.

3.1 Channel usage matrix

For efficient operations of the network, number of data structures are used of which major is Channel Usage Matrix (CUM). Table 1 shows sample of CUM where CHN is used to denote Channel number and MN is used to denote Mobile Node. Each node has its own CUM table and its entries indicate available channels. A binary value 0 means channel is busy and 0 indicates that the channel is available.

3.2 Connection establishment

In the proposed system, parallel rendezvous scheme has been used for channel negotiation, selection and control. Each host is capable of making independent channel selection and routing decisions. Figure 5 presents the working system of the same. Each host uses CUM for finding the free channel. RTS is the request to send and CTS is the clear to send packets for channel reservation. After looking into CUM, most reliable channel is chosen and channels reservation process is initiated. Each node performs channel control and data transmission. A host can be active at the multiple channels at the same time as shown in Fig. 5, node 1 and node 6 are trying to make channel reservation on channel 1 whereas node 3 and node 8 are performing data transmission on channel 3. Detailed

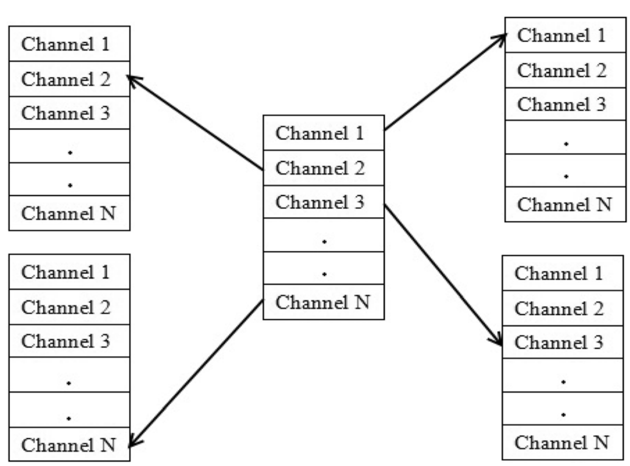


Fig. 3 Multi-channels in PRMMAC

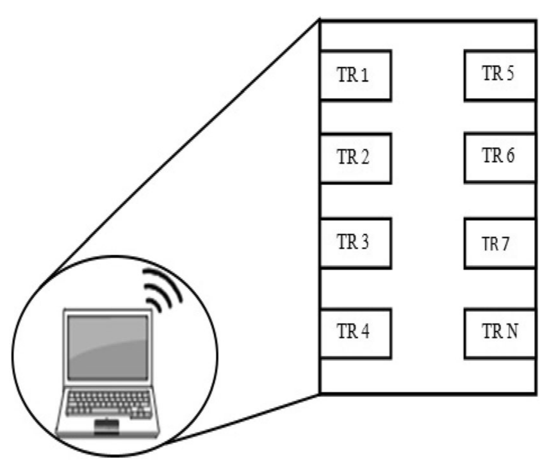


Fig. 4 NIC with multiple transceivers

Table 1 Channel usage matrix

	CHN_1	CHN_2	CHN_3	CHN_n
MN_1	0	1	1	0
MN_2	0	0	0	0
MN_3	1	1	1	1
MN_n	1	1	1	1

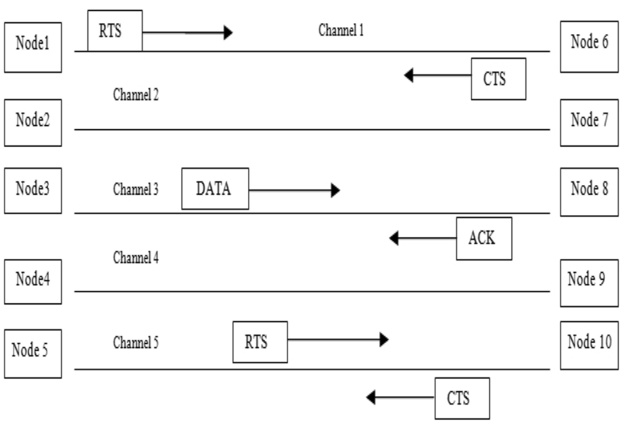


Fig. 5 Connection establishment process

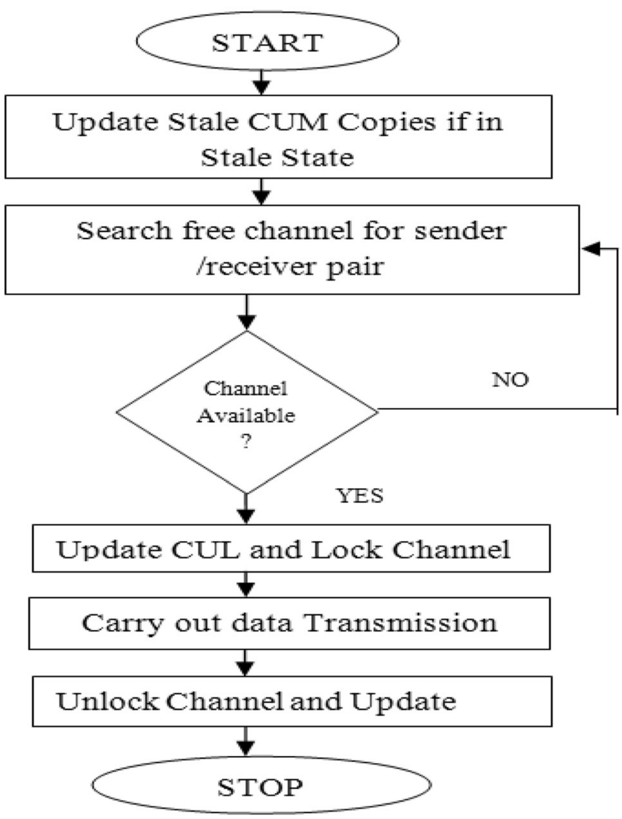


Fig. 6 Flowchart for channel negotiation and allocation

channel selection procedure is presented with the help of a flowchart in Fig. 6.

3.3 Network operating modes

Depending upon the traffic, different network modes can be chosen for efficient and streamlined network operation. For ensuring optimized and energy efficient operation following network operating modes can be chosen:

i. Low Traffic Mode: In this mode, only a single channel is used for communication and only one or two transceivers are active and rest are in doze mode. This mode is used only if the traffic density is quite low to ensure low energy consumption and improved network lifetime.
ii. Moderate Traffic Mode: In this mode, more than one channels are used for communication and number of channels to be used depends upon the volume of traffic. If the traffic increases, new channel is added and if the traffic is reduced then one channel is removed. Channels are added and removed in increment factor of one at a time.
iii. High Traffic Mode: In this mode, all the channels are active and full parallel mode is supported. This mode is suitable if simultaneous parallel transmission is required or when multiple node wants to communicate with a single node or when high volumes of data is required to be transmitted.

3.4 Load balancing mechanism

In multi-channel environment, number of channels are available for communication. If the traffic on these channels is not maintained properly, chaos and under-performance can plague the network. Traffic should be distributed uniformly across all the channels. In the proposed protocol, the metric used to balance the load is based on the number of re-transmissions. In this approach, each node maintains a sorted vector containing the number of re-transmissions observed by each node on each channel. The channel which has the least number of re-transmissions is chosen if available [40, 41]. Table 2 provides sample contents used for selecting a channel by a given node.

Each node before making channel decision will first consult the re-transmission vector and proceeds to next phase. The values in re-transmission table can be updated by control packet (Network Management Protocols) or can be updated by the node itself.

Table 2 Re-transmission count

Channel number	Re-transmission value/coefficient
0	8
1	10
2	12
3	21
4	35
5	45
N	…

4 Performance evaluation

4.1 Simulation model

For evaluating and validating the proposed protocols, large number of nodes are used ranging from 50 to 1000. An area of 1000 × 1000 m is used wherein these nodes can move and initiate data communication. Each node produces data at constant bit rate (CBR) and is equipped with a standard omni-directional antenna. MCMSim simulator and test-bed [38] has been used for performance evaluation. This tool offers multifaceted capabilities for performance evaluation of multi-channel ad hoc networks. Detailed simulation parameters are presented in Table 3. Each simulation is carried for 10 s and is repeated nearly hundred times. The results presented are average of all these simulations.

For verifying the performance of the proposed protocol exhaustive throughput analysis has been done with varied tunable simulation parameters.

Table 3 Simulation parameters

Parameter	Value
Number of channels	3
SIFS/DIFS/Slot time	16 µs/34 µs/9 µs
A-ACK	16 Bytes
RTS	16 bytes
Basic rate	1 Mbps
Data rate	2 Mbps
Data packet size	512 Bytes
Retry limit	4
Transmission range	250 m
Transmit/receive power consumption	1.65 W/1.4 W
Idle/doze power consumption	1.15 W/0.045 W
No. of available channels	3

4.2 Performance comparison

To establish the efficacy of the proposed system it has been thoroughly contrasted and compared with existing standard protocols. For evaluation, existing protocols have been used for performance comparison of the system [37]. In major simulations throughput has been take as a primary criterion for performance evaluation. The impact on mobility on the throughput has been exhaustively measured and compared. The mobility has been increased from 2 m per second to 6 m per second. In addition to it Frame Delivery Ration (FDR) and impact of delay has been measured and compared [39].

4.3 Throughput analysis

To show the strength and efficiency of the proposed protocol comprehensive throughput analysis has been done. Numerically throughput is calculated using the following formula.

$$Throughput = \frac{Packet\_size * No\_successfulPackets}{Total\_SimTime}$$

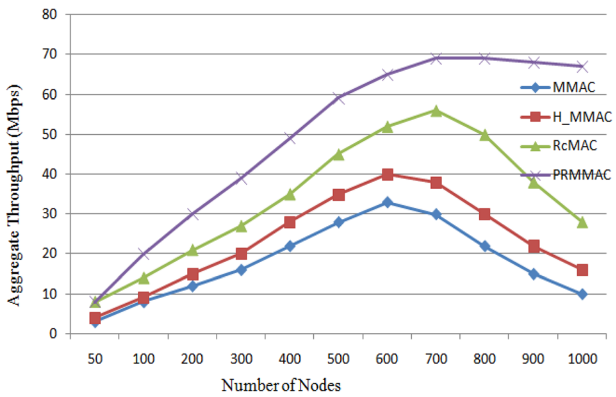
This formula calculates number of packets successfully transmitted per unit of time. All simulations have been carried out for minimum of 10 s. The results shows average results obtained for 20 simulations under the similar setup. For detailed evaluation the system has been compared with existing standard protocols which include RcMAC [34], MMAC [28] and H_MMAC [36]. In all the graphical results, MMAC is represented by blue colored lines, H_MMAC by red colored lines, RcMAC by green colored lines and the proposed PRMMAC by purple colored lines.

For effective evaluations, throughput has been observed at different mobility rates. In present case, throughput has been observed at mobility rate of 2, 4 and 6 m per second. Figure 7a, b and c present the results and throughput comparison with different protocols. From the results, it can be seen that the mobility has adverse impact on throughput of the system. It can also be seen that the proposed protocol provides higher throughput rates than the other protocols.

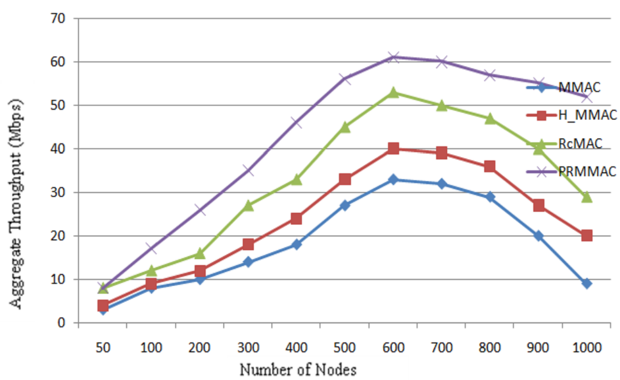
4.4 Frame delivery ratio (FDR)

One other performance parameter used for performance comparison is frame delivery ratio. Formula for calculating FDR is given below. For computation of FDR the mobility rate has been kept at 0.5 m/per second.

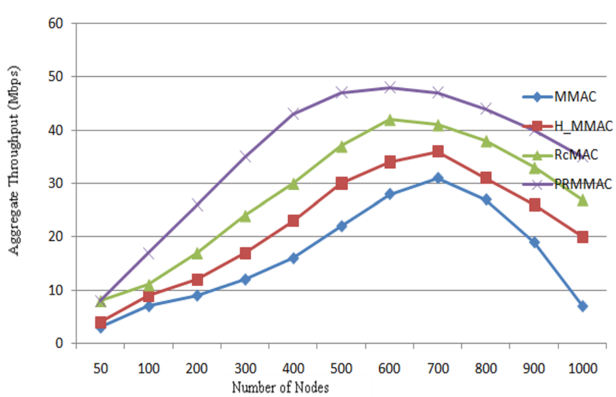
$$Frame\_Delivery\_Ratio = \frac{Frame\_Received\_By\_Receiver}{Frame\_Generated\_By\_Sender}$$



(a) Throughput Comparison, Speed 2m/sec



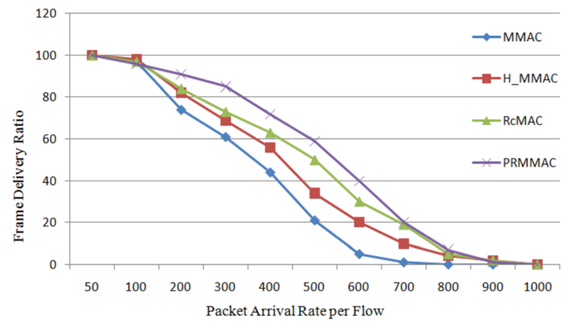
(b) Throughput Comparison, Speed 4m/sec



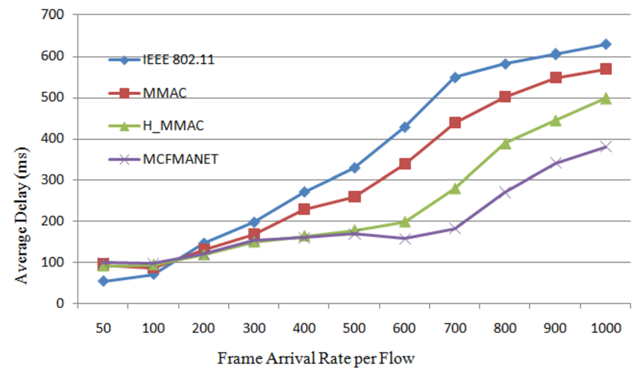
(c) Throughput Comparison, Speed 6m/sec

Fig. 7 Throughput comparison, **a** speed 2 m/s, **b** speed 4 m/s, **c** speed 6 m/s

The proposed PRMMAC exhibits significant improvements in terms of FDR in comparison to its counterparts. On an average minimum performance gain of 18% is observed as shown in Fig. 8a.



(a) FDR Analysis, Speed 0.5m/sec



(b) Delay Analysis, Speed 0.5m/sec

Fig. 8 **a** FDR analysis, speed 0.5 m/s; **b** delay analysis, speed 0.5 m/s

4.5 Delay analysis

Other performance parameter measured is delay. The formula for observing delay is given below.

$$Average\_Delay = \frac{Total\_Paket\_Delay}{No\_of\_Successful\_Packets}$$

Rate of mobility for delay measurement have been kept at 0.5 m/s.

PRAMMAC exhibits at least 10% minimum delay in comparison to other protocols as shown in Fig. 8b. The reduction in delay provides vital performance gains especially for large size communications and data transfer.

4.6 Performance analysis for six channels

For validating the efficacy of the proposed system the framework has also been tested using six channel framework. Table 4 presents the detailed simulation parameters.

4.7 Throughput analysis using six channels

Throughput has been measured similarly as done for 3 channel configuration. The rate of mobility has been kept at 1 m per second. Throughput comparison under new configuration has been presented in Fig. 9. It can be seen that

Table 4 Simulation table

Parameter	Value
Number of channels	6
Rate of mobility	1 m/s
SIFS/DIFS/Slot time	16 µs/34 µs/9 µs
A-ACK	16 Bytes
RTS	16 bytes
Basic rate	1 Mbps
Data rate	2 Mbps
Data packet size	512 Bytes
Retry limit	4
Transmission range	250 m
Transmit/receive power consumption	1.65 W/1.4 W
Idle/doze power consumption	1.15 W/0.045 W

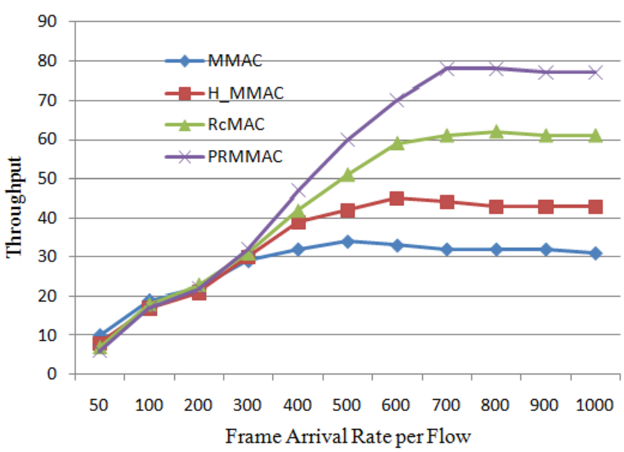


Fig. 9 Throughput analysis using six channels at mobility rate of 1 m/s

the proposed protocol outperforms other protocols of its class. On average the proposed system achieves 20% better performance in terms of throughput than its counterpart protocols.

4.8 Frame delivery ratio (FDR) analysis using six channels

FDR being a vital parameter has been measured using six-channel framework. The mechanism of measurement has been similar to that of three channel setup. Results of FDR analysis has been presented in Fig. 10. The proposed protocol achieves better FDR that its counterparts. On average performance gain of more than 25% is achieved using the proposed framework.

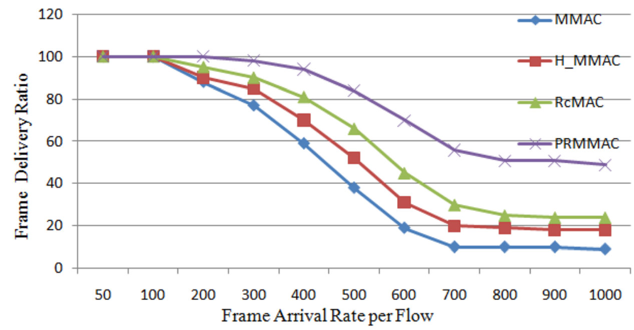


Fig. 10 FDR analysis using six channels at mobility rate of 1 m/s

4.9 Delay analysis using six channels

Delay analysis of the proposed system under six channel configurations has also been done on similar pattern as that of three channel setup. Analysis of delay has been presented in Fig. 11. The proposed system has been able to achieve performance improvement of 35–56% in comparison to other protocols.

5 Conclusion

In this paper, Parallel Rendezvous Multi-Channel MAC (PRMMAC) protocol to resolve saturation of control channel and to ensure the balanced load among various channels have been proposed and evaluated. The protocol developed supports parallel rendezvous mode for channel negotiation and data transmissions. The proposed system is easy to implement as tight synchronization among nodes is not required. For performance comparison, the developed framework has been evaluated alongside different standard-benchmarked protocols and from the results it can be seen that it outperforms other protocols in term of throughput and efficiency. Detailed throughout analysis under different mobility rates has been carried out and the

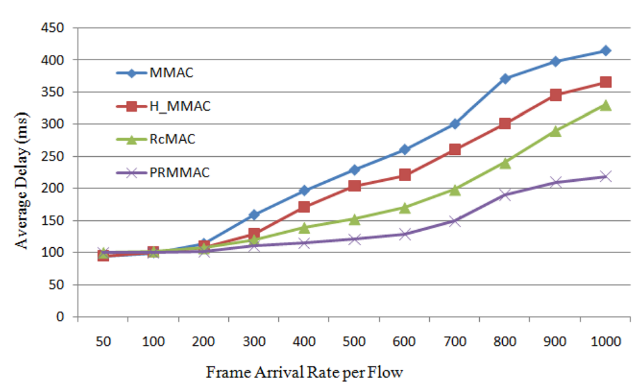


Fig. 11 Delay analysis using six channels at mobility rate of 1 m/s

proposed work exhibits significant improvement over existing protocols. Alongside, throughout delay and FDR has also been observed. The proposed protocol provides increased throughput in between 5 to 14 Mbps at different mobility rates in comparison with other protocols. Future work can be done to reduce channel access time and contention. Further, with the application of cognitive radio performance, overall system efficiency can be improved.

References

1. So J, Vaidya N (2004) Multi-channel mac for ad hoc networks: handling multichannel hidden terminals using a single transceiver In: Proceedings of ACM MobiHoc, 2004, pp 1–12
2. Chen J, Sheu S, Yang C (2003) A new multichannel access protocol for IEEE 802.11 ad hoc wireless LANs. In: Proceedings of IEEE PIMRC, 2003, pp 1–6
3. Tzamaloukas A, Garcia-Luna-Aceves JJ (2000) Channel-hopping multiple access. In: Proceedings of IEEE ICC, 2000, pp 1–7
4. Tzamaloukas A, Garcia-Luna-Aceves JJ (2000) Channel-hopping multiple access with packet trains for ad hoc networks. In: Proceedings of IEEE Mobile Multimedia Communications, 2000, pp 26–35
5. So H, Walrand J, Mo J (2007) McMAC: a parallel rendezvous multi-channel (MAC) protocol. In: Proceedings of IEEE WCNC, pp. 1–10
6. Bahl P, Chandra R, Dunagan J (2004) SSCH: slotted seeded channel hopping for capacity improvement in IEEE 802.11 ad-hoc wireless networks. In: Proceedings of ACM MobiCom, 2004, pp 1–15
7. Patel J, Luo H, Gupta I (2007) A cross-layer architecture to exploit multi-channel diversity with a single transceiver. In: Proceedings of IEEE INFOCOM Minisymposium, 2007, pp 1–5
8. Shi J, Salonidis T, Knightly E (2006) Starvation mitigation through multi-channel coordination in CSMA multi-hop wireless networks. In: Proceedings of ACM MobiHoc, pp 1–12
9. Luo T, Motani M, Srinivasan V (2009) Cooperative asynchronous multichannel MAC: design, analysis, and implementation. IEEE Trans Mob Comput 8(3):338–352
10. Wu S, Lin C, Tseng Y, Sheu J (2000) A new multi-channel MAC protocol with on demand channel assignment for multi-hop mobile ad hoc networks. In: Proceedings of I-SPAN, 2000, pp 232–238
11. Cao M, Raghunathan V, Kumar P (2006) Cross-layer exploitation of (MAC) layer diversity in wireless networks. In: Proceedings of IEEE ICNP, 2006, pp 1–22
12. Al-Meshhadany T, Ajib W (2007) New CDMA-based MAC protocol for ad hoc networks. In: Proceedings of VTC, Fall, 2007, pp 91–96
13. Chen W, Huang T, Chang Y, Liu J (2006) An adaptive multi-channel MAC protocol for wireless ad hoc networks. In: Proceedings of IEEE ICC, 2006, pp 4541–4545
14. Wu S, Tseng Y, Lin C, Sheu J (2002) A multi-channel MAC protocol with power control for multi-hop mobile ad hoc networks. Comput J 45(1):101–110
15. Jain N, Das S, Nasipuri A (2001) A multichannel CSMA MAC protocol with receiver based channel selection for multihop wireless networks. In: Proceedings of IEEE IC3N, 2001, pp 432–440
16. Maheshwari R, Gupta H, Das S (2006) Multichannel MAC protocols for wireless networks. In: Proceedings of IEEE SECON, 2006, pp 141–156
17. Zhang J, Zhou G, Huang C, Son S, Stankovic J (2007) TMMAC: an energy efficient multi-channel MAC protocol for ad hoc networks. In: Proceedings of IEEE ICC, 2007, pp 1–8
18. Huang R, Zhai H, Zhang C, Fang Y (2008) SAM-MAC: an efficient channel assignment scheme for multi-channel ad hoc networks. ComputNetw 52(8):1634–1646
19. Chen F, Zhai H, Fang Y (2009) An opportunistic multiradio MAC protocol in multirate wireless ad hoc networks. IEEE Trans Wireless Commun 8(5):2642–2651
20. Tanigawa Y, Tode H, Murakami K (2010) Multi-channel MAC protocols with two transceivers pursuing effective use of vacant resources. In: Proceedings of IEEE CCNC, 2010, pp 1–8
21. IEEE Computer Society (2007) Part 11: wireless LAN medium access control (MAC) and physical layer (PHY) specifications. IEEE Standard 802.11, 2007, pp 1–256
22. Lo FL, Ng TS, Yuk TI (1997) Performance of multichannel CSMA networks. In: Proceedings of IEEE International Conference on Information Communications and Signal Processing, 1997, pp 1045–1049
23. Zhou G, Huang C, Yan T, He T, Stankovic J, Abdelzaher T (2006) MMSN: multifrequency media access control for wireless sensor networks. In: Proceedings of the 25th Annual Joint Conference of the IEEE Computer and Communication Societies, 2006, pp 1–13
24. Nasipuri A, Das SR (2000) Multichannel CSMA with single transcreiver power-based channel selection for multihop wireless networks. In: Proceedings of the 52nd IEEE Vehicular Technology Conference (VTC-Fall'00), 2000, pp 211–218
25. Nasipuri A, Zhuang J, Das SR (1999) A multichannel CSMA-MAC protocol for multihop wireless networks. In: Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC'99), 1999, pp 1402–1406
26. Wang J, Fang Y, Wu D (2006) A power-saving multi-radio multi-channel MAC protocol for wireless local area networks. In: Proceedings of the 25th Annual Joint Conference of the IEEE Computer and Communication Societies (Infocom'06), 2006, pp 1–12
27. Shi J, Salonidis T, Knightly EW (2006) Starvation mitigation through multi-channel coordination in CSMA multi-hop wireless networks. In: Proceedings of the Seventh ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc'06), 2006, pp 214–225
28. So J, Vaidya N (2004) Multi-channel MAC for ad hoc networks: handling multichannel hidden terminal using a single transceiver. In: Proceedings of the Fifth ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc'04), 2004, pp 222–233
29. Jain N, Das SR, Nasipuri A (2001) A multichannel MAC protocol with receiver based channel selection for multihop wireless networks. In: Proceedings the 10th International Conference on Computer Communications and Networks (ICCCN'01), 2001, pp 432–439
30. Wu SL, Lin CY, Tseng YC, Sheu JP (2000) A new multi-channel MAC protocol with on-demand channel assignment for multi-hop mobile ad hoc networks. In: Proceedings of the International Symposium on Parallel Architectures Algorithms and Networks (I-SPAN'00), 2000, pp 232–237
31. Garcia-Luna-Aceves JJ, Raju J (1997) Distributed assignment of codes for multihop packet-radio networks. In: Proceedings of the Military Communication Conference (Milcom'97), 1997, pp 450–454
32. Tang Z, Garcia-Luna-Aceves JJ (2009) Hop-reservation multiple access (HRMA) for ad hoc networks. In: Proceedings of the 18th

Annual Joint Conference of the IEEE Computer and Communications Societies (Infocom'99), 2009, pp 194–201
33. Tzamaloukas A, Garcia-Luna-Aceves JJ (2001) A receiver-initiated collision avoidance protocol for multi-channel networks. In: Proceedings of the 20th Annual Joint Conference of the IEEE Computer and Communications Societies (Infocom'01), 2001, pp 189–198
34. Hwang J, Kim T, So J, Lim H (2013) A receiver-centric multichannel MAC protocol for wireless networks. ComputCommun 36(2013):431–444
35. Cetinkaya C (2015) Multi-channel cooperative MAC protocol for wireless LANs. Ad Hoc Netw 28(1):17–37
36. Dang DNM, Hong CS, Lee S (2015) A hybrid multi-channel mac protocol for wireless ad hoc networks. WirelNetw 1(2):387–404
37 Kavita T, Taneja H, Kumar R (2018) Multi-channel medium access control protocols: review and comparison. J Info OptimizSci 39(1):239–247
38. Kumar R, Taneja K, Taneja H (2019) MCMSim test-bed for multi-channel MAC framework For MANET. Int J ComptSciEng 7(1):457–462
39. Kumar R, Taneja K, Taneja H (2018) Performance evaluation of MANET using multi-channel MAC framework. ProcComptSci 133(2018):755–762
40. Singh VK, Kumar R (2018) Multichannel MAC scheme to deliver real-time safety packets in dense VANET. ProcComptSci 143(2018):712–719
41. Singh VK, Kumar R (2019) An optimized multichannel MAC scheme with dynamic control channel interval in dense VANET. Int J Info Technol 11(3):411–419
42. Cheng W et al (2018) Full-duplex for multi-channel cognitive radio ad hoc networks. IEEE Network 33(2):118–124
43. Dorin R, Dhaou R, Chaput E (2019) Initial placement optimization for multi-channel UAV networks. In: Proceddings of International Conference on Ad-Hoc Networks and Wireless. Springer, Cham, 2019, pp 1–12
44. Mojtaba V, Ding Z, Poor HV (2019) Multiple access techniques for 5G wireless networks and beyond. Springer, pp 1–692