Performance Evaluation of Reuse Common Control Channel

Khaled Hatem Almotairi

Department of Computer Engineering, Umm Al-Qura University

Al Taif Road, 24382 Makkah, Saudi Arabia

Email: khmotairi@uqu.edu.sa

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Khaled Hatem Almotairi

Department of Computer Engineering, Umm Al-Qura University

Al Taif Road, 24382 Makkah, Saudi Arabia

Email: khmotairi@uqu.edu.sa

Abstract:

Using the dedicated control channel approach in multi-channel environments can improve the network performance and does not require clock synchronization. However, when the number of channels is few, it increases the overhead, and, therefore, limits the performance. Thus, some researchers suggest to reuse the control channel to transfer data packets when all data channels are busy. In this paper, we develop an analytical model to investigate the advantages and disadvantages of the reuse of the control channel. Simulation results are also presented to validate the analytical model and to study the performance under different settings. In addition, we show the results of the dedicated control channel approach for comparison.

INTRODUCTION:

The capacity of wireless networks is limited due to interference. Leveraging multiple channels can improve the network performance because multiple transmissions can take place on multiple channels (e.g., Wi-Fi networks have three orthogonal channels in the 2.4-GHz band and 12 channels in the 5-GHz band [1]).

Many multi-channel medium access control (MMAC) protocols have been proposed in the literature, and there are different approaches of how to utilize the available channels [2], [3]. Different classifications can be applied to MMAC protocols, e.g., principle operation and synchronization requirement. Following [2], [3], the first approach is common hopping MMAC protocols in which all nodes follow the same hopping sequence and hop between channels, and it requires tight global clock synchronization. The second, split phase MMAC protocols divide time into slots, and each slot has two phases. The first phase is the control phase in which all nodes meet on a predefined control channel to make agreements. In the second phase (the data phase), successful pairs tune to their agreed upon channels and exchange data [3], [4]. This approach also requires global clock synchronization. Parallel rendezvous MMAC protocols are another approach that requires clock synchronization.

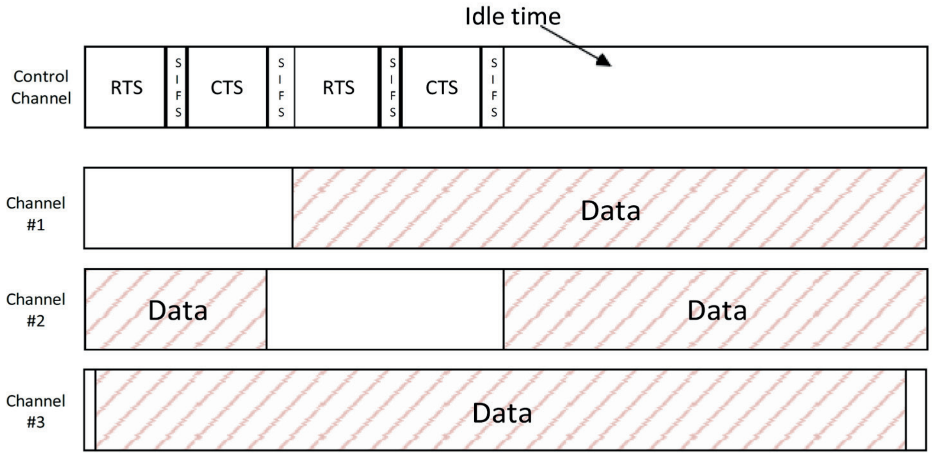
This approach outperforms all other approaches in terms of the network performance because multiple devices can meet and transmit on different channels at the same time.

Finally, common channel MMAC protocols in which one channel is common for control and broadcasting packets and the remaining channels are data channels for data transmission do not require clock synchronization. However, when the number of channels is large, this approach suffers from the congestion on the control channel [5], [6]. When the number of channels is few, the common control channel becomes an overhead. We can further classify this approach into two mechanisms based on the use of the common channel. The first mechanism known as the dedicated control channel (DCC) MMAC protocols that is when the common channel is dedicated for control and broadcast packets, i.e., no data packets are transmitted over the common control channel [7], [8]. In DCC, devices exchange control packets on the control channel to reserve data channels. When all data channels are busy, the dedicated control channel becomes idle as shown in Fig. 1a. The Dynamic Channel Assignment (DCA) protocol is proposed for multi-hop networks [9]. Two interfaces are installed on each node. One interface is fixed on the control channel, and the other interface switches between data channels. Using multiple channels with transmission power control (TPC) will increase the network capacity [10], [11]. The second mechanism known as the reuse of control channel (RCC) MMAC protocols is when the common channel is for control and broadcast packets and reused for data transmission if all data channels are busy. The RCC mechanism has been suggested in [12], [13] and proposed in [14]. It seems that the RCC mechanism resolves the overhead of the common control channel when the number of channels is few. A recent comparison between multi-channel MAC protocols is given in [5]. [15] and [16] provide certain multi-channel issues and present some existing multi-channel MAC protocols.

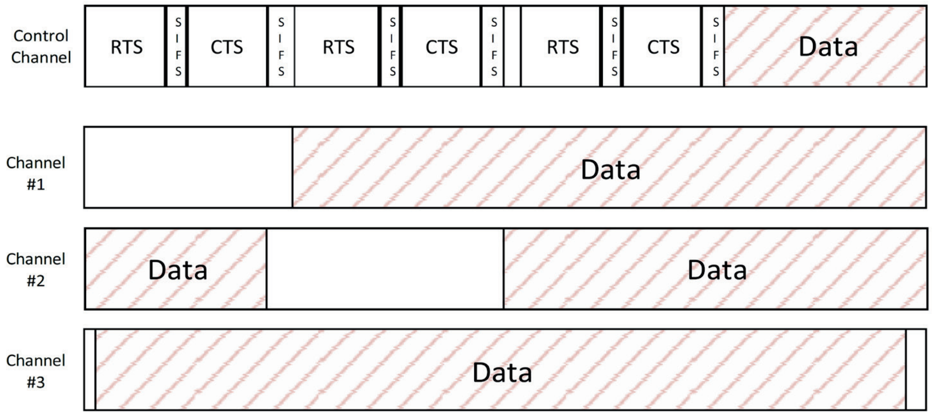
Our objective is to investigate whether or not the reuse of the common control channel for data transfer improves the network performance or not because the performance of dynamic multi-channel approach is not well investigated yet. The term channel reuse of common channel is that the common channel is used not only for control and broadcast packets, but also for data transmission if all data channels are busy. It is unknown when allocating the entire bandwidth for common control channel for only control packets may improve the network performance. Alternatively, reusing the common control channel not only for control packets but also for data transmission when all other channels are occupied and may improve the channel utilization.

In this paper, we develop an analytical model, based on a bi-dimension Markov chain model, for the RCC scheme. The theoretical results are validated with the simulation results, and we then compare the results with the DCC mechanism, which has been developed in [5]. The purpose of this comparison is to study the advantages and disadvantages of the reuse of the common control channel for data transmission.

The remainder of the paper is organized as follows. Section II describes the RCC and DCC mechanisms. An analytical model is developed in Section III while numerical and simulation results are given in Section IV. Finally, we conclude the paper in Section V.



(a) DCC



(b) RCC

Fig. 1. Comparison of the DCC and RCC mechanisms.

II. RCC AND DCC

In this section, we describe the RCC and DCC mechanisms. In DCC, there is one dedicated control channel used for transferring control packets (i.e., request-to-send (RTS) and clear-to-send (CTS) packets), and there are data channels used for data communication. Any device that has a packet to transmit must compete on the dedicated control channel to reserve a data channel by transmitting an RTS packet on the dedicated control channel. Once receiving the RTS, the destination responds with a CTS packet on the control channel, confirming the data channel. Then, the source transmits the data packet on the agreed data channel as shown in Fig. 1a. The common control channel is either the bottleneck when the channels are large or overhead when the channel is small.

To overcome the overhead of the common control channel when the channels are small, some researchers suggest to reuse the common control channel to transfer data packets when all data channels are busy, i.e., the RCC mechanism [12]–[14]. The mechanism is similar to DCC, and the only difference is that when all data channels are busy, any device can reuse the control channel to transmit its data packet as shown in Fig. 1b. It is beneficial when the number of channels are few, e.g., three channels as discussed below.

III. ANALYTICAL MODEL

In this section, we describe and analyze simplified models of the RCC mechanism1. There is one common control channel and Md is the number of data channels, all with equal bandwidth, i.e., $M = M_d + 1$ is the total channels. With perfect synchronization, time is divided into small slots, and the slot size t is equal to the time to exchange RTS/CTS packets to make an agreement. N wireless devices and a single collision domain with perfect channel condition are assumed, and all the devices are in saturated mode. We assume that the packet lengths, which are integer multiples of slot durations, are independent and geometrically distributed with parameter q, which is, packet duration with a mean of $1/q$ slots.

We assume an ideal slotted ALOHA, and an idle device attempts to transmit with probability p in the next slot by exchanging of the RTS/CTS packets. To reserve a data channel, the devices compete on the common control channel, and they can transmit only one packet. When all data channels are busy, the devices are allowed to reuse the control channel to transmit their data packet with the packet length, which is independent and geometrically distributed with parameter β. Although the distribution of both packet length transmitted on the control channel and the data channels is the same, the mean packet length used on the data channels (i.e., 1/q slots) is not the same as the mean packet length used on the control channel (i.e., $1/\beta$ slots).

These assumptions and simplifications allow us to construct a two-dimensional discrete-time Markov model to study the throughput of the protocol. Let $X(t)$ represent the number of communicating pairs at slot time t, (e.g., when $X(t) = k$, $2k$ devices are involved in data transfer, while the other $N - 2k$ devices are idle), and the state space of $X(t)$ is {0, 1, . . . , M_d}. In addition, $C(t)$ represents the state of the common control channel whether it is used for data transmission or not at time t. Thus, the state space of $C(t)$ is {0, 1} (e.g., when $c(t) = 0$, the common control channel is not used for data transmission because some data channels are unused or there is no successful transmission to reserve it at time t). Therefore, $\{X(t), C(t)\}$ is a two-dimensional discrete-time Markov chain, its state is:

$$\begin{aligned} S = \{&(0, 0), (1, 0), \ldots, (\min(\lfloor N/2 \rfloor, Md), 0), \\ &(\min(\lfloor N/2 \rfloor, Md), 1), \ldots, (1, 1), (0, 1)\}. \end{aligned} \tag{1}$$

Let $T_K^{(j)}(t)$ represent the probability that j transfers terminate over the data channels at time t giving that there are k transfers at time $t-1$, such that $k \geq j$, and is given by the following:

1In **[5]**, the analytical model of the DCC mechanism has been develop, and, therefore, we follow the same assumptions and notations. Note that there is an error in transition probabilities of the DCC model in [5], and it is corrected in [17]

$$\begin{aligned} T_k^{(j)} &= Pr[j \text{ transfers terminate at time } t | X_{t-1} = k] \\ &= \binom{k}{j} q^j (1-q)^{k-j}. \end{aligned} \tag{2}$$

For the common control channel, the probability that the data transmission over the common control channel terminates at time t is denoted by I = β

Let $S^{(i)}$ denote the probability that i new agreements are made. Since the common control channel approach is based on the Single Rendezvous protocol, at most one transfer is allowed in the next slot **[2], [3]**. An agreement is made when exactly one idle device attempts to transmit an RTS on the control channel. Hence, the success probability $S^{(i)}$ in the next time slot, given that k pairs are communicating in the current slot^k, is:

$$S_k^{(i)} = \begin{cases} (N-2k)p(1-p)^{(N-2k-1)}, & \text{if } i = 1; \\ 1 - S_k^{(1)}, & \text{if } i = 0; \\ 0, & \text{otherwise.} \end{cases} \tag{3}$$

Let $P\{l, h|k, f\}$ be a one-step transition probability of the Markov chain from state (k, f) at time t to (l, h) at time $t + 1$.

A state changes only when a new agreement is made or existing transfers end. In the following, we will express the transition probability based on the state of the common control channel. The transition probability $P\{l, 0|k, 0\}$ is the probability that k transfers terminate at time t and l pairs in the next slot, and the common control channel is not used for data transmission. It is given as follows:

$$P\{l,0|k,0\} = \begin{cases} 0, & \text{if } l > k+1; \\ T_k^{(0)} S_k^{(1)}, & \text{if } l = k+1; \\ T_k^{(k-l)} S_k^{(0)} & \\ +T_k^{(k-l+1)} S_k^{(1)}, & \text{if } (0 < l \leq k) \\ & \text{and } (l + k \neq 2M_d); \\ T_k^{(k)} S_k^{(0)}, & \text{if } l = 0. \end{cases} \tag{4}$$

The following probability is that when all data channels are occupied, a new agreement is made to use the common control channel for data transfer.

$$P\{l,1|k,0\} = T_k^{(k-l)} S_k^{(1)} \qquad \text{if } (l = k+1) \text{ and } (l+k = 2M_d). \tag{5}$$

The probability $P\{l, 0|k, 1\}$ indicates the transition probability when the data transfer over the common control channel terminates and can be obtained as

$$P\{l,0|k,1\} = \begin{cases} 0, & \text{if } (l > k+1); \\ T_k^{(k)} S_k^{(0)} \mathcal{I}, & \text{if } (l = 0); \\ T_k^{(0)} S_k^{(1)} \mathcal{I}, & \text{if } (l = k+1); \\ T_k^{(k-l)} S_k^{(0)} \mathcal{I} & \\ +T_k^{(k-l+1)} S_k^{(1)} \mathcal{I}, & \text{if } (0 < l \leq k). \end{cases} \tag{6}$$

The following probability indicates that the data transfer over the common control channel is not terminated in the next slot regardless the status of other data channels (e.g., some data channels may become idle, but since the control channel is busy, no agreements can be made)

$$P\{l,1|k,1\} = \begin{cases} 0, & \text{if } (l \geq k+1); \\ T_k^{(k-l)}(1-\mathcal{I}), & \text{if } (0 \leq l \leq k); \\ & \text{and } l+k \neq 2M_d; \\ T_k^{(k-l)}(1-\mathcal{I}) & \\ +T_k^{(k-l)} S_k^{(1)} \mathcal{I}, & \text{if } l+k = 2M_d. \end{cases} \tag{7}$$

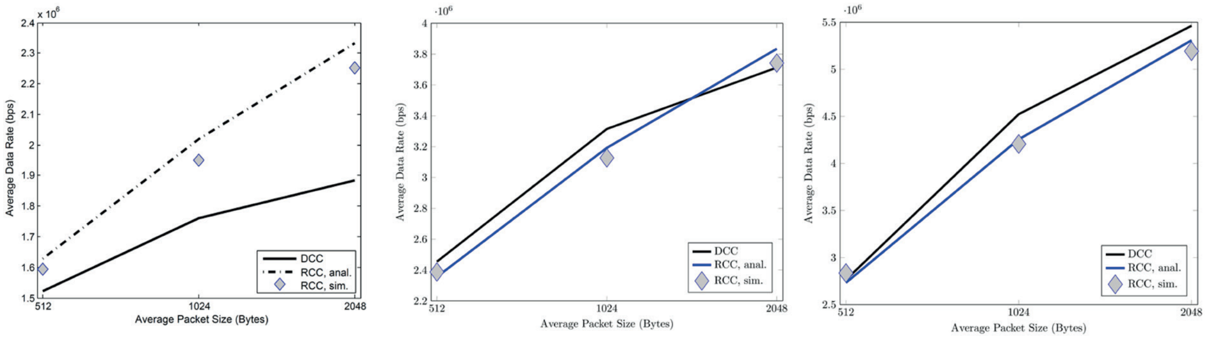
The average utilization of all channels including the common control channel can be obtained as:

$$\rho = (\sum_{i,j \in \mathcal{S}} \sum (i+j)\pi_{ij})/M, \tag{8}$$

Where πij is the limiting probability that the system is in states i and j and S is the state space of the Markov chain. We obtain the system throughput R as

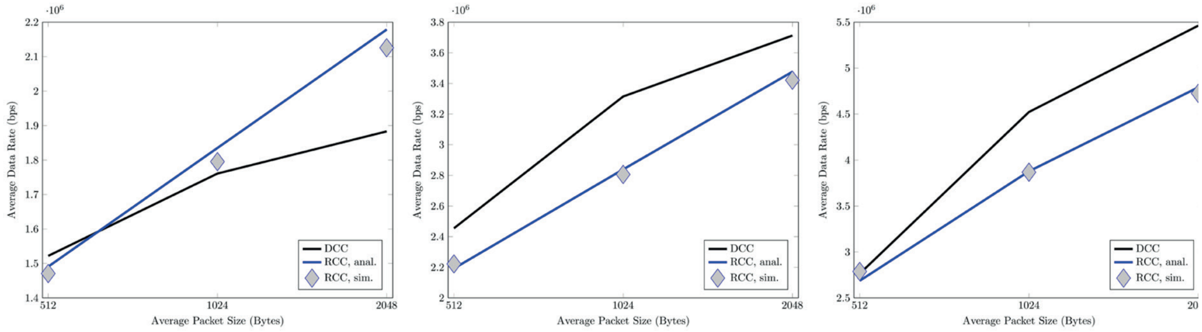
$$R = MC\rho,$$

where C is the channel capacity and ρ is the data channel utilization that we calculate using (8).



(a) 3 Channels (b) 5 Channels (c) 7 Channels

Fig. 2. Comparison of the DCC and RCC schemes with different channels when the the mean packet length is 512 bytes transferred over the control channel



(a) 3 Channels (b) 5 Channels (c) 7 Channels

Fig. 3. Comparison of the DCC and RCC schemes with different channels when the mean packet length is 1024 bytes transferred over the control channel.

IV. NUMERICAL RESULTS

In this section, we develop a packet-level simulation using Matlab to validate the analytical model of RCC presented in the above section. In addition, the results are compared with the DCC model developed in **[5].** We consider a single-hop Ad Hoc network with a number of wireless devices, and each device always has a packet in its queue for transmission. A single collision domain with perfect channel condition is assumed. A simple modification can be applied for imperfect channel, but it does not change the findings. The system parameters are listed in Table I, and the channel bit rate of all channels is set to 1Mbps. The number of devices is set to 30, and the duration of each slot is the time to transmit the RTS and CTS packets, which, according to the parameters, is equal to $RTS + SIFS + CTS + SIFS = 288 + 10 + 240 + 10 = 548\ \mu s$.

We choose two different average packet sizes transferred on the control channel for the RCC scheme to study the impact of control channel occupancy on the network performance. Fig. 2 shows the throughput results with different average packet lengths transferred on data channels (x-axis) and for different numbers of channels when the average packet size transferred on the control channel is set to 512 bytes. Each device can randomly select their packet lengths according to the geometrically distribution as discussed in Section III.

PHYhdr (bits)	128
SIFS (μs)	10
Channel bit rate (R)	1 Mbps
RTS Packet Size (bits)	160 + PHYhdr
CTS Packet Size (bits)	112 + PHYhdr

TABLE I SYSTEM PARAMETERS

control channel is set to 512 bytes. Each device can randomly select their packet lengths according to the geometrically distribution as discussed in Section III.

Fig.2a shows that the simulation results match well with the analytical values of the RCC approach when the number of channels is 3. We can also see that the RCC approach outperforms the DCC approach because the RCC use all the channels efficiently when the packets are longer.

The throughput results of the RCC approach degrade because some data channels become idle while the control channel is busy when the number of the channels increases to 5 and 7 as shown in Fig.2b and Fig.2c, respectively. In addition, the DCC achieves slightly higher throughput than the RCC when the packets are short.

Fig.3 shows the numerical results when the packet size increase to 1024 bytes transferred on the control channel. When the number of channels is 3, the RCC performs better than the DCC when the packets are longer as shown in Fig.3a. However, DCC achieves better throughput than RCC when the channels are large, as shown in Fig.3b and in Fig.3c when the number of channels is 5 and 7, respectively. Because devices take longer time using the control channel for their data transfer under RCC, it affects the performance.

CONCLUSION

In this paper, we develop an analytical model using a bi-dimensional Markov chain to investigate the performance of reusing the control channel when all data channels are busy in the multi-channel environments. Simulation results are used to validate the analytical results under different settings. In addition, we compare the numerical results with the control channel dedicated for control packets. Our results conclude that reusing the control channel to transmit data packets if all data channels are busy does not help to improve the network performance instead it increases the control channel bottleneck when the channels are larger. In many proposed protocols [12], broadcast packets that are transmitted on the control channel also limit the performance for both approaches (i.e., the RCC and DCC).

REFERENCES

- IEEE-SA Standards Board, "IEEE Std. 802.11-2007; Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," June 2007.

- K. Almotairi and X. Shen, "A distributed multi-channel MAC protocol for ad hoc wireless networks," IEEE Trans. on Mobile Computing, vol. 14, no. 1, pp. 1–13, Jan. 2015.

- J. So and N. H. Vaidya, "Multi-channel MAC for ad hoc networks: handling multi-channel hidden terminals using a single transceiver," in Proc. of ACM MobiHoc, 2004, pp. 222–233.

- J. Lee, J. Mo, T. M. Trung, J. Walrand, and H.-S. So, "Design and analysis of a cooperative multichannel mac protocol for heterogeneous networks,"

IEEE Trans. on Vehicular Technology, vol. 59, no. 7, pp. 3536–3548, 2010.

- J. Mo, H.-S. So, and J. Walrand, "Comparison of multichannel MAC protocols," IEEE Trans. on Mobile Computing, vol. 7, no. 1, pp. 50–65, Jan. 2008.

- T. Luo, M. Motani, and V. Srinivasan, "Cooperative asynchronous multichannel MAC: Design, analysis, and implementation," IEEE Trans. on Mobile Computing, vol. 8, no. 3, pp. 338 –352, March 2009.

- K. H. Almotairi and X. Shen, "Multichannel medium access control for ad hoc wireless networks," Wireless Communications and Mobile Computing (Wiley), vol. 13, no. 11, pp. 1047–1059, 2013.

- C. Han, M. Dianati, R. Tafazolli, X. Liu, and X. Shen, "A novel distributed asynchronous multichannel mac scheme for large-scale vehicular ad hoc networks," IEEE Trans. on Vehicular Technology, vol. 61, no. 7, pp. 3125–3138, 2012.

- S.-L. Wu, C.-Y. Lin, Y.-C. Tseng, and J.-L. Sheu, "A new multi-channel MAC protocol with on-demand channel assignment for multi-hop mobile ad hoc networks," in Proc. of Int. Symp. Parallel Architectures, Algorithms and Networks (ISPAN), 2000, pp. 232–237.

[10] K. H. Almotairi and X. Shen, "Symmetrical power control for multi-channel multi-hop wireless networks," in Proc. of IEEE Global Telecommunications Conference (GlobeCom), Miami, FL, USA, 6-10 December 2010.

- S.-L. Wu, Y.-C. Tseng, C.-Y. Lin, and J.-P. Sheu, "A multi-channel MAC protocol with power control for multi-hop mobile ad hoc networks," The Computer Journal, vol. 45, no. 1, pp. 101–110, 2002.

- R. Huang, H. Zhai, C. Zhang, and Y. Fang, “SAM-MAC: An efficient channel assignment scheme for multi-channel ad hoc networks,” Computer Networks, vol. 52, no. 8, pp. 1634–1646, 2008.

- K. H. Almotairi and X. Shen, “Distributed power control over multiple channels for ad hoc wireless networks,” Wireless Communications and Mobile Computing (Wiley), vol. 13, no. 18, pp. 490–516, 2013.

- D. Sardana and Q.-A. Zeng, “Control-channel-reuse-based multiple-channel mac (CRM-MAC) for ad hoc networks,” in Computational Science and Engineering, 2009. CSE ’09. International Conference on, vol. 2, Aug. 2009, pp. 133–139.

- J. Crichigno, M.-Y. Wu, and W. Shu, “Protocols and architectures for channel assignment in wireless mesh networks,” Ad Hoc Networks, vol. 6, no. 7, pp. 1051 – 1077, 2008.

- P. Kyasanur, J. So, C. Chereddi, and N. Vaidya, “Multichannel mesh networks: challenges and protocols,” Wireless Communications, IEEE, vol. 13, no. 2, pp. 30–36, April 2006.

- P. Pawelczak, S. Pollin, H.-S. So, A. Bahai, R. Venkatesha Prasad, and R. Hekmat, “Performance analysis of multichannel medium access control algorithms for opportunistic spectrum access,” IEEE Trans. on Vehicular Technology, vol. 58, no. 6, pp. 3014–3031, July 2009.

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