An RTS Based Data Channel Reservations and Access Scheme in Multi-Channel Systems

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Abstract. In Multi-channel systems control packets handshake reserves both control and data channels where a dedicated control channel is implemented. RTS and CTS packets should sense the medium and agree on a specific data channel. The process is long and it wastes resources when there is no agreement. We propose an RTS based channel reservation and access scheme. The CTS agrees with RTS to reserve a specific data channel without sensing the medium to reduce reservation delay. Data channel reservation is done when a data channel is available. The paper first presents a scalable channel switching scheme. Numeric results show that the channel switching scheme is efficient and scalable. Furthermore, the simulation results show that when the utilization of data channels is restricted to seventy-five percent, the RTS based scheme performs better. The seventy-five percent threshold is when the data flows constitute three quarters of the number of the data channels.

Keywords: Contention; Control Channel; Channel Switching; Channel Utilization; Data Channels; Network Capacity.

1 Introduction

The paper investigates two techniques through which the access networks can be enhanced and scaled up under given constraints associated with wireless systems. The techniques are the channel switching and the data channel reservation techniques. Wireless communication systems offering broadband wireless access to the Internet backbone are required. Various techniques have been proposed and investigated. One of the techniques that has been widely investigated is the Multi-channel scheme. However, the implementation of the multi-channel techniques comes with the channel switching delay challenge that requires urgent solution. The channel switching delay has been largely explored as a challenge that affects the performance of access networks. We characterize channel switching delay as a scalable function that equips the control channel and improves its capacity. We also implement an RTS based channel access and reservation technique. The paper answers the question whether limiting channel contention to the common control channel will unlock more capacity for multi-channel systems.

The paper discusses two techniques, the channel switching and the RTS based channel reservation and access schemes. In the channel switching scheme, the channel

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switching delay is re-configured and associated with the data channels. This enables the control channel to have more capacity and to drive more data channels. The channel switching technique factors in the double effect of the channel switching penalty. In addition to the normal data transmission time, the data channel will be further unavailable for two channel switching durations. In the meantime, the control channel will be able to schedule more data flows to other idle data channels.

Lastly, we attempt to further improve the channel switching scheme by implementing the RTS based data channel reservation and access scheme. The main objective is to reduce the amount of time taken by a communicating pair in reserving both the control and the data channel. The scheme is likely to result in numerous packet collisions taking place. To minimize the effect of these collisions, data channel reservation will be initiated during specific timeslots when data channels are idle. A multi-channel cyclical scheduling algorithm equipped with network support is being investigated as a possible solution.

The reminder of the paper is organized as follows: Section 2 justifies the need for a scalable multi-channel scheme for the access networks which offer high capacity. The related work is discussed in section 3. The system model is presented and discussed briefly in section 4. The two proposed schemes are analyzed in section 5 and numerical results are also presented for discussion in this section. Section 6 presents and discusses our future work. The paper is then concluded in section 7.

2 Motivation

Multi-channel wireless communications offer increased bandwidth and flexibility. Optimized techniques can avail more capacity to handle quality of service requirements of time bounded and sensitive packets. Multi-channel systems scalable and can be integrated with multi-radio systems for improved capacity, flexibility, robustness and more scalability.

Furthermore, multi-channel techniques that implement a dedicated common control channel facilitate connectivity in multi-channel wireless networks. Terminals listen on the common control channel when idle. They can also exchange control packets on the control channel when they wish to reserve a data channel. It is envisaged that this multi-channel architecture will provide an enabling platform for the implementation of our complete multi-channel scheme.

3 Related Work

Future wireless networks such as the wireless sensor networks, ad hoc networks and wireless mesh networks (WMN) are envisioned to be self organizing and bandwidth efficient [1]. WMN satisfy the first requirement and more research is required to ensure that the second requirement is also met. The second requirement of wireless networks can be met through the implementation of the multi-channel schemes however; queuing delay of Multi-channel systems should be reduced. Secondly, the requirement can also be met by improving the scalability of WMN. Queuing delay minimization and the improvement of the scalability of WMN is the focus of this paper.

Wireless networks suffer from numerous interferences which degrade significantly the capacity of these networks; as a result they become less bandwidth efficient. The CDMA technique is ideal for such collision environments given its interference averaging and resistance properties. CDMA provides a collision free medium access which is ideal for network systems which are designed to be bandwidth efficient [2]. It was shown in [3] that when CDMA is run on top of TDMA it improves single hop throughput and it also reduce the amount of transmission power; however it requires more processing power. In [4] CDMA and TDMA schemes are cited as interesting research topics and possible solutions to bandwidth inefficient wireless systems. CDMA and TDMA will be explored in our future work after we have designed a scalable and bandwidth efficient multi-channel systems.

In [4], multi-channel techniques are considered as possible future research directions. The authors suggested that for multi-channel techniques to be bandwidth efficient, they should include single channel solutions which solve the scalability issues of WMN. We are pursuing a similar line of thinking. In our case we will first design a scalable multi-channel scheme before we implement the scheme in multi-channel and multi radio systems.

The multi-channel systems are degraded significantly by the channel switching delay which can be as large as 224µs [4]. The sensing duration is specified to be 15µs in [5] [6]. In our approach we seek to reduce significantly both the sensing duration and the channel switching delay related to the sensing of data channels. We are also interested in reducing the queuing delay, packet loss and at the same time improving the scalability of WMN [4]. For detail survey of the challenges of MAC protocols and possible future directions of research in this field, readers are referred to [4] [7] [8].

The main challenge of multi-channel systems relates to the coordination and scheduling of the available channels. Therefore good and smart strategies that coordinate the use of channels in an efficient way at the same time ensuring that there is total network connectivity are sought after. The cost of hardware should also be considered in the design of multi-channel systems. The multi-channel systems should be cost effective and less complex.

In [9] a system employing busy signals is proposed. The scheme assumes that a transceiver can listen on all the available channels simultaneously. A scheme proposed in [10] is TDMA based and it requires global clock synchronization. The scheme proposed in [11] segments a network into logical partitions. Nodes in [12] randomly select home channels to listen on when idle. This approach also segments a network and does not facilitate network connectivity for effective communication. A receiver directed transmission in [13] relies on quiescent channels which in essence partitions a network. We consider a common control channel for network connectivity.

The Slotted Seeded Channel Hopping scheme in [14] is time based and its performance is affected by a need for global time synchronization. The Dynamic Channel Assignment in [15] uses two transceivers and is expensive in terms of hardware costs. In our work we employ a single transceiver.

In [16] a dedicated control channel approach is reported to be causing a bottleneck and that it is capacity constrained. However, the control channel scheme facilitates network connectivity. Our analysis in [17] showed that the control channel has enough capacity and that its capacity can further be improved by the channel switching penalty. We therefore implement a scheme equipped with a single transceiver with a dedicated common control channel.

In [18] an RTS is sent with a list of free data channels including a preferred data channel. Upon receiving the RTS, the receiver will first check whether any of the data channels in the received RTS packet is free. The receiver will send a confirming CTS if one of the channels is free. The terminals in this setup contend for both data and control channels. Our approach seeks to limit channel contention to the control channel and to reduce the time taken in reserving both the control and data channels. The reduction of the channel reservation duration will improve the performance of the network.

The work in [18] also associates the channel switching delay with both control and data channels. The effect of the channel switching delay was not included in the main results. It was treated separately, where its value was varied between 0µs and 5000µs. We associate the channel switching delay with data channels. The value of the channel switching delay is set to 448µs to simulate the double effect of the channel switching penalty. The channel switching parameter is included in the simulation to show how it degrades the achieved throughput.

We proposed a cyclical scheduling algorithm (CSA) in [19] and [20] a framework which provides a platform for the implementation of the channel reservation and access technique we are proposing in this paper. The proposed CSA is not discussed in this work. In this paper we discuss the channel access and the reservation scheme and also show how the channel switching technique improves the capacity of the control channel. The novelty of this paper is in the implementation of the channel contention scheme which excludes the data channel contention component. A communicating pair which manages to reserve a control channel, reserve automatically a given idle data channel.

The channel switching delay technique is not discussed in detail in this work. It is presented to show how it relates and compares to the reservation scheme. The channel reservation scheme is an incremental work to the channel switching delay technique. The numerical results of the reservation scheme show an improvement on the channel switching technique.

4 System Model

The model under investigation is twofold. We briefly present the channel switching model first then the RTS based data channel reservation and access model. The channel switching model presents the channel switching penalty as a positive challenge which equips the control channel with more capacity to drive more data channels. The RTS reservation scheme seeks to reduce the channel reservation duration.

We assume that there are at least three channels altogether, and that more data channels are available. We recognize that there are only three or four orthogonal channels [21]. However, to test the scalability of the system we assume that all the channels are orthogonal. We therefore consider four data channels in our experimentation. We also assume that all terminals listen on the control channel when idle and that data transmission is scheduled in phases; this is an attribute of the CSA. A general topology with six nodes consisting of three communicating pairs resulting in three data flows is considered. The network size is then increased from the initial three data flows to fifteen data flows.

For the channel switching model, terminals will incur a channel switching delay of 224µs when switching to the reserved data channel. After exchanging successfully the data and ACK packets, the terminals will switch back onto the control channel incurring another channel switching delay of 224µs. The total channel delay will be therefore set to 448µs. The control channel will be reserved as and when as the data channels become available. Network support is assumed to equip terminals with intelligence to know when data channels would be next available for reservation.

It is anticipated that the utilization of the control channel will increase as more data channels are added. However, an upper bound is anticipated when the control channel would saturate [19] [20]. The performance of the control channel is expected to improve with the increase in data channels until it reaches its saturation point. This architecture facilitates the scalability of the model and also ensures that the control channel drives more data channels.

Lastly, we present the RTS based data channel reservation and access model. The model is based on the architectural framework discussed above and it is an enhancement of the channel switching scheme. It assumes that the sender during time *T* to *T1* will take *T1 – T* duration to sense the medium and identify all the idle data channels before sending out an RTS packet with a preferred data channel. It is also assumed that the receiver will spend the same amount of time sensing the channels before agreeing with the sender. When both the sender and the receiver sense the medium, the sensing duration will be doubled. If the receiver will be expected to dispatch the CTS packet without sensing the channels, the sensing duration will be reduced. This will give the control channel more capacity to schedule more data flows to other available data channels.

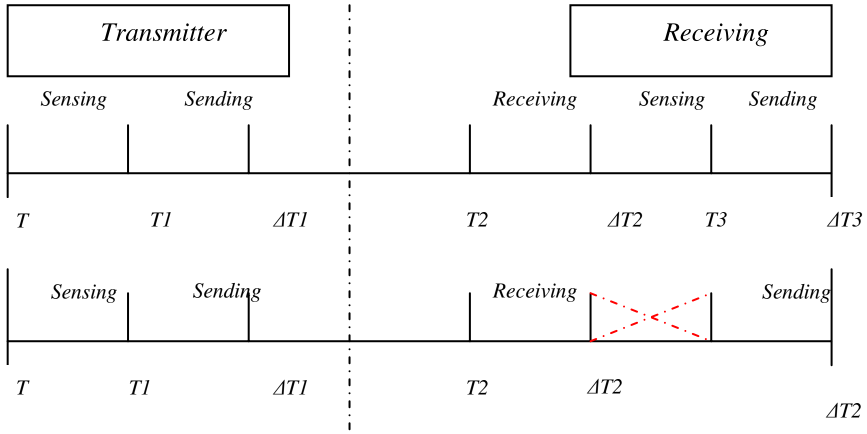

Fig. 1. The analysis of the data channel reservation and access technique

Fig 1 is divided into the transmitter and the receiver sections. It shows in general terms what processes the two terminals engage on before reserving a data channel. The transmitter has to first identify all idle data channels and send the list to the receiver including its preferred data channel. The receiver will also upon receiving the RTS packet, check whether the sender's preferred data channel is also free at its end. It may check other data channels in the list if the preferred data channel is not available. Thereafter, it will send either the confirming or the rejecting CTS packet back to the transmitter. This whole process is captured in the top block in Fig 1.

The bottom block shows a proposed approach where a sender does not have to first sense all the data channels. The sender only includes one data channel in its RTS packet which is known to be idle and the receiver would be expected to accept it. The receiver will agree with the sender on the preferred data channel without having to first sense the medium. The sender can choose a preferred data channel without sensing the medium when a fully functional network support is implemented. The data channels will be known when they would be idle without relying on both physical and virtual carrier sensing mechanism. *T, T1, …, T3* denotes hypothetical times. However, in the experimentation, sensing of data channels was limited to the transmitter.

The implementation of the RTS based data channel reservation assumes that the data channel would be available when the sender reserves the control channel. The receiver will therefore be expected to agree with the sender on the preferred data channel identified by the sender. The probability of collisions will approach zero as more data channels are made available. However, the rate of packet collisions will increase when data channels are few. The number of the data channels should be sufficiently large for better system performance. We will demonstrate this property through simulations and probabilistic models in the next section.

5 Simulation Model and Numerical Results

The simulation environment consisted of four data channels and one control channel. The bandwidth of all the channels was set to 2 Mbs. The NOAH routing protocol was implemented. The default NS 2.8 parameters and values were not changed; including those specified in [18] our reference model. The value of the channel switching delay was set to 448μs. The number of data flows was increased from three to fifteen in all the experiments which were conducted. The size of the network was varied to effectively test the scalability of the proposed schemes. The maximum number of data flows employed in the experimentation does not indicate the upper bound of the proposed technique but was informed by our analysis in [20]. The upper bound of the scheme will be investigated further in our future work.

For each network size, the simulation was run at least five times with each simulation running for three hundred simulation seconds. All data packets are assumed to be of type CBR and are all 1072 bytes long including headers. The generation of packets is exponentially distributed. Both data and control packets are sent between a sender and a receiver. The network is assumed to be single hop, hence packets are not relayed. The RTS and CTS packets are sent on the control channel which is set aside as a signalling channel, while the DATA and ACK packets are sent on the data channels. The timers are reconfigured and reset accordingly. We also take into account two switching delays when a terminal switches from the control channel to the data channel and then back to the control channel. Each channel switching delay is assumed to be 224μs, giving a combined channel switching delay of 448μs. The rest of the parameters were set to values specified in the IEEE 802.11 standard.

The following acronyms were used in this experimentation: CC_sw, DC_sw and DC_cont. CC_sw depicts a channel switching delay approach associated with the control channel, the reference model, the DC_sw stands for the data channel switching approach and DC_cont depicts the channel access scheme proposed in this paper. In the proposed channel access, contention is limited to the control channel. The access to data channels is associated and linked to the control channel reservation.

Fig 2 and 3 show the performance of the channel switching scheme in two networks with five and fifteen data flows respectively. A data flow connects two communicating pairs. The size of the network is always twice the number of data flows. For example in a network with five data flows, there are ten nodes under consideration.

The performance of the switching channel technique improved with the increase in the size of the network as shown in Fig 3. The number of data flows in Fig 2 constituted a sixth of those in Fig 3, but the achieved throughput in Fig 3 is higher. The two results show that the channel switching scheme is scalable and that it performs reasonable well in large networks. The efficiency of the control channel improves when either the size of the network or the number of data channels is increased.

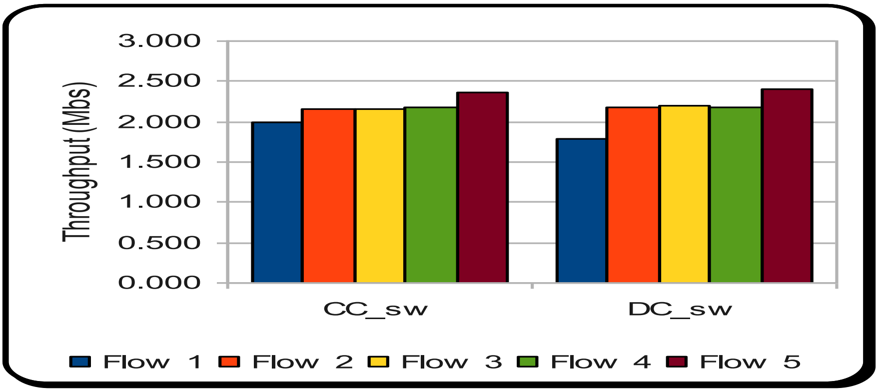

Fig. 2. The evaluation of the channel switching technique in a network with five data channels

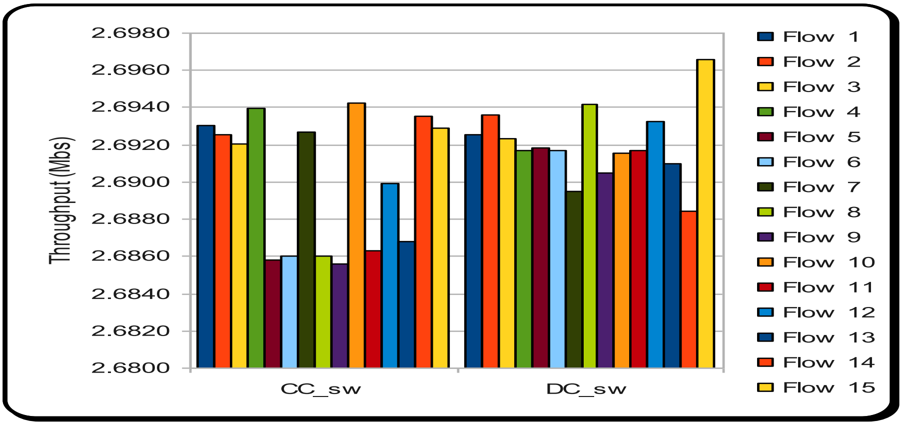

Fig. 3. The performance of the channel switching technique in a network with fifteen data channels

It can also be seen in the two results that the proposed channel switching technique outperformed the one implemented in [18], our reference model. In Fig 2, the proposed channel switching technique was outperformed only in the first data flow, while in Fig 3 it was poor in five data flows. Considering the ratio of data flows where the new channel switching technique was outperformed; in Fig 2, we have a 1 in 5 while in Fig 3, the ratio is 1 in 6. The ratios show an improvement in performance of the channel switching technique in Fig 3 and its scalability.

The proposed channel switching technique was then included in the implementation of the RTS based data channel reservation and access technique. We preview the performance of the RTS technique and then try to give insight as to why it did not do well in large networks. We present part of the results of the experiments of this scheme. Lastly, we briefly evaluate the impact of the proposed RTS based scheme on packet collisions and dropping.

The RTS scheme with an enhanced channel switching technique was compared with the performance of the enhanced channel switching technique without the RTS scheme. The enhanced channel switching technique was first compared with the scheme proposed in [18] and was found to be superior and more scalable.

In Fig 4, the RTS based scheme performed better in the first data flow and was outperformed in the second data flow. The differences are not significant in both cases. However, in Fig 5, the proposed RTS based scheme was clearly dominant. It performed better in the first and in the third data flow. It was outperformed in the second data flow.

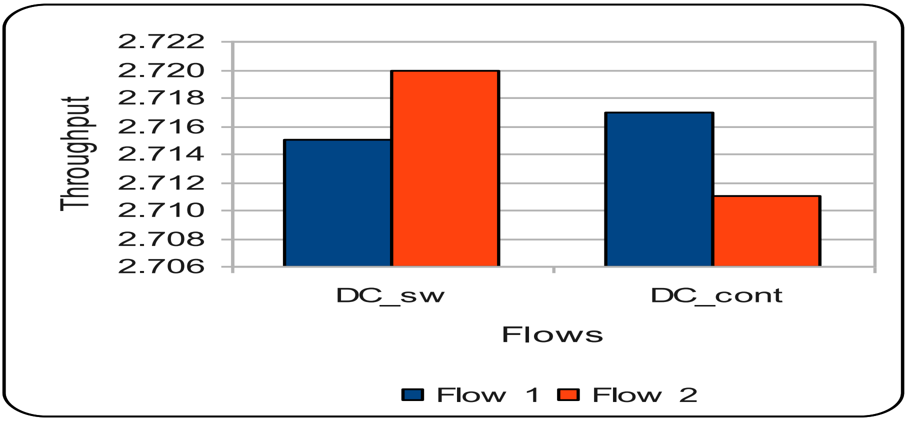

Fig. 4. The performance of the RTS based reservation scheme in a network with only two data flows

When the network size was increased beyond the three data flows, the performance of the RTS based scheme was severely degraded. For example when the number of data flows was either equal to or more than the number of data channels, the RTS based data channel reservation and access scheme crashed. This was caused by an increase in the amount of interference as the size of the network was increased.

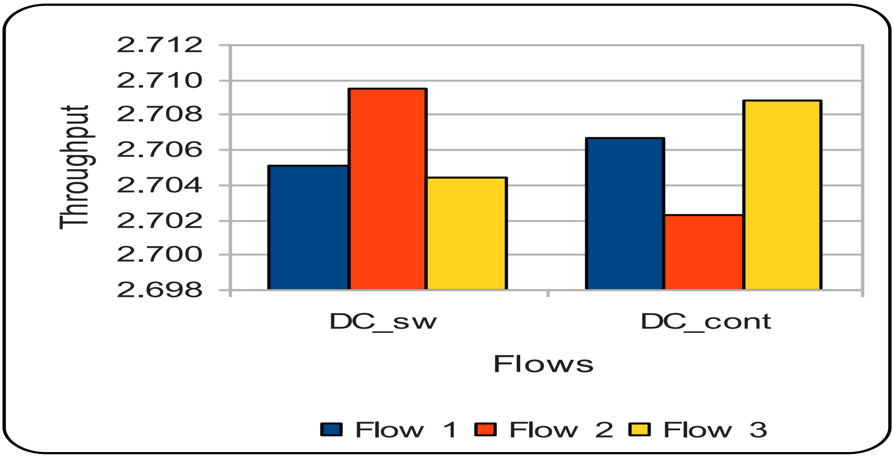

Fig. 5. The results of the RTS based scheme in a network with three data flows

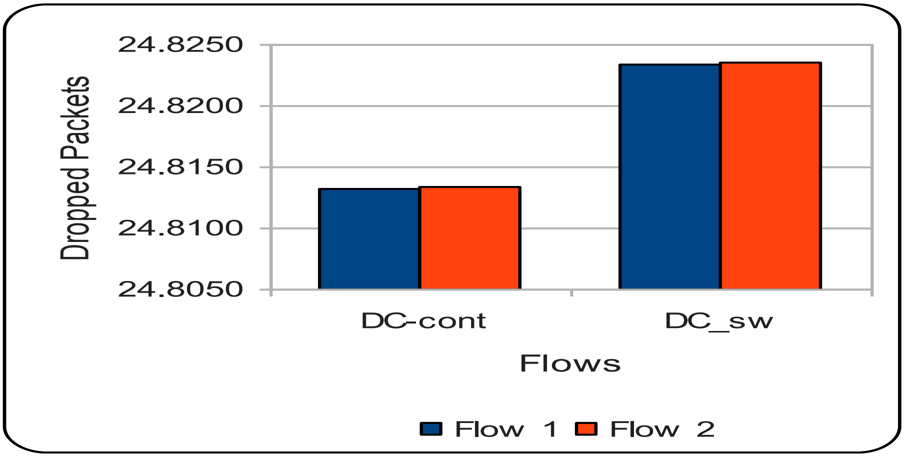

Fig. 6. Total number of packets dropped in a two data flows scenario

The RTS based scheme performs better when the size of the network is kept small and crashed when it was increased. It can therefore be concluded that the proposed data channel access scheme is ideal for small networks. The number of data flows in any given time should be restricted to three quarters of the number of the available data channels if better network performance is desired. The upper bound of this scheme is when the number of data flows is kept at seventy-five percent of the available data channels. In our experimentations reasonable results were obtained up to a network with three data flows with four data channels. The performance of the scheme degraded significantly when the number of data flows was increased to four and beyond.

To provide more insight to the performance of the RTS based scheme, we evaluated the impact of delay on the rate of packet dropping. The analysis shows that the proposed scheme dropped fewer packets when the amount of the interference was low and then dropped more packets when the amount of the interference increased with the increase in the size of the network.

In Fig 6 and 7, there were two data flows running at any given time. However in the case of Fig 7 the second data flow was split into two, where the second transmitter was transmitting to two different receivers at different times. In both scenarios, the proposed technique recorded fewer packet losses. The RTS based scheme lost fewer packets in both data flows in Fig 6. In Fig 7, both techniques lost the same number of packets for the first two data flows. The RTS scheme then lost fewer packets in the third data flow. The amount of lost packets has a bearing on the performance of the scheme. A scheme which loses fewer packets performs better and it shows that is suffered from minimum queuing delay. In the two scenarios the RTS scheme dropped fewer packets and thus performed better.

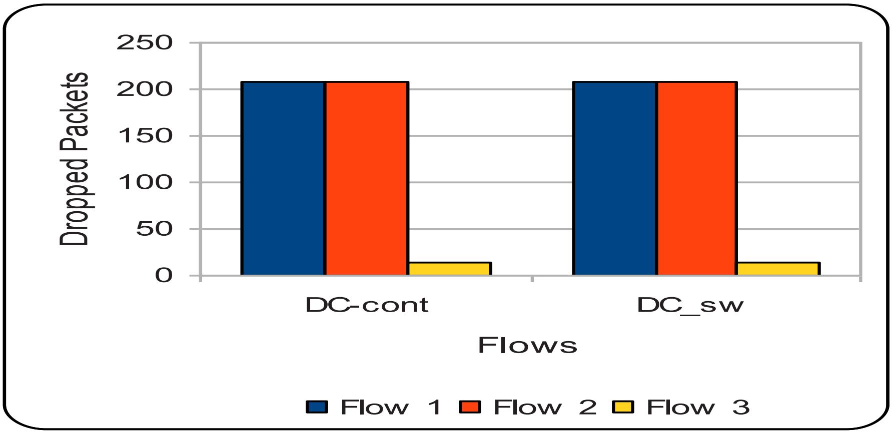

Fig. 7. Number of packets dropped in a network with two transmitters and three receivers

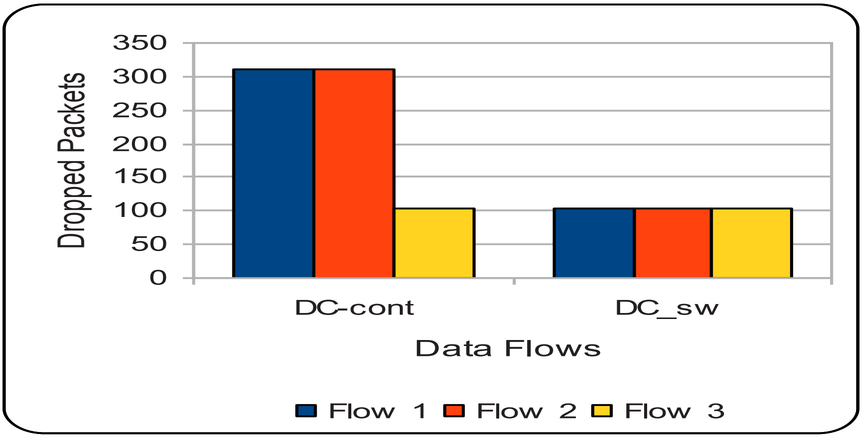

Fig. 8. Number of packets lost in a network with three data flows

Fig 8 depicts a transition in the performance of the RTS based scheme. The performance of the scheme began to degrade, though it performed better in achievable throughput. In contrast, it recorded heavier packets loses in the first two data flows, and it then recorded the same amount of packet loses with the reference model in the third flow.

We now examine the results were the proposed scheme crashed. When the number of data flows was equal to the number of data channels, a significant degradation was observed in the RTS scheme. In Fig 9 the data flows were increased to four. The number of the data flows was equal to the number of data channels. The amount of interference also increased sharply affecting the RTS scheme severely. As a result, the proposed reservation scheme recorded a huge loss in data packets and a significant number of control packets were also dropped. The dropping of control packets had a severe impact on the performance of the reservation scheme. The losses were very high in all the four data flows as compared to the few packets dropped by the reference model. As a result the reference model outperformed the RTS scheme with a wide margin.

The results in Fig 9 show that the number of data flows should be restricted to seventy-five percent of the number of the available data channels for the RTS scheme to offer better performance. The scheme therefore performs well in small networks and should be restricted to small networks.

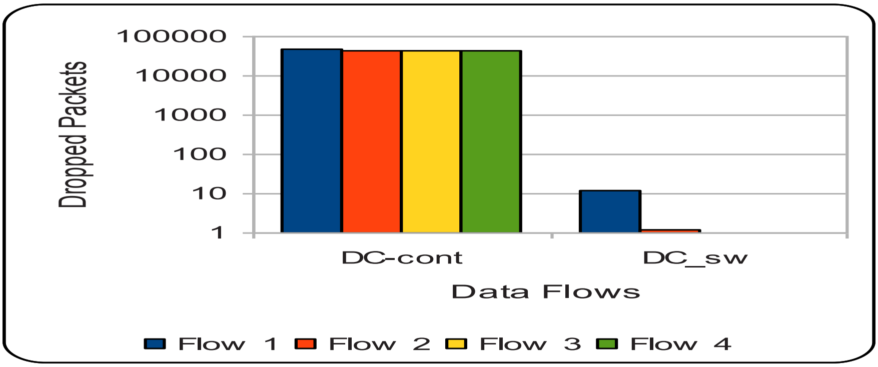

Fig. 9. Number of packets dropped in a network with four data flows

In this paper we implemented the reservation scheme at the receiver end. It was not implemented in the sending terminal. The modifications and improvements of the scheme will extend the proposed scheme to the transmitter end. The implementation of the scheme at the receiving terminal produced interesting results which need to be further analyzed. The results show the improvement in performance when the number of data flows constitutes seventy-five percent of the number of data channels.

The performance of the reservation scheme degraded significantly when the number of data flows was equal to or more than the number of data channels. To understand and explain why the performance of the reservation scheme seems to relate to and is affected by the number of data channels, we employed a modest probabilistic technique.

We evaluated the effects of the availability of data channels in every cycle. We noted that the probability of all data channels being available at the beginning of a given cycle is one or closer to one. However, as we approach the end of the cycle, the probability of data channel availability approaches zero. This means that a new data flow has a high chance of reserving a data channel at the beginning of the cycle than it would at the end of the cycle. The degree of data channel availability therefore affects the performance of the reservation scheme in that sense. The performance of the scheme is good when more data channels are available and very poor when very few data channels are idle.

Table 1 depicts the probabilities that, x data channels are available duration different phases of a given cycle. For example, in a four data channel system, the probability that all data channels are available at the beginning of the transmission phase is 1.0. The probability of the availability of data channels reduces to 0.25 at the end of the cycle after most data channels are taken during the course of the cycle.

The analytical and probabilistic data in Table 1, can be represented graphically to depict possible performance attributes of the reservation scheme. The data in Table 1 is represented in Fig 10. As it can be seen in Fig 10, the performance of the scheme will degrade marginally from the beginning of the cycle to the end of the cycle. Thereafter, it will degrade significantly as shown by Fig 9 above. It should also be noted that the reservation scheme was compared with our channel switching scheme which was proved to be more scalable and bandwidth efficient. The small improvement in the reservation scheme shows a further improvement of our framework, the CSA. The improvement of the reservation scheme can be better appreciated if its performance is compared with [18]

Table 1. The Availability of Data Channels duration each cycle

Number of Nodes	4	3	2	1
Probability	1.0	0.75	0.5	0.25

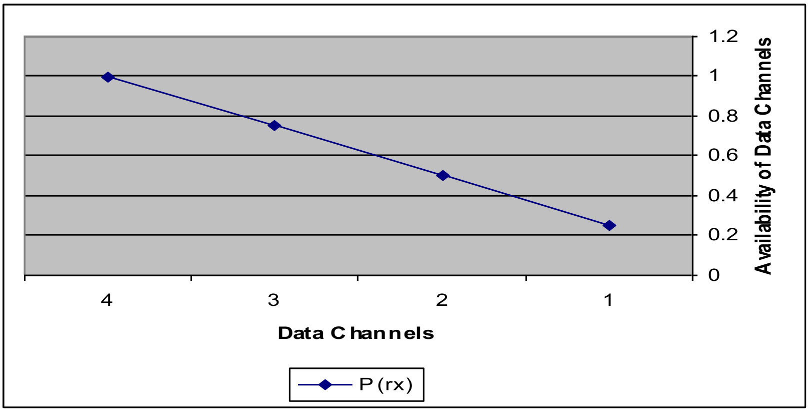

Fig. 10. The availability of data channels during a given transmission cycle

The performance of the reservation scheme according to the results presented in this paper can be improved further by adding more data channels to the network. However, it should also be noted that the reservation scheme was not fully implemented in this work. It was implemented in the receiver end. The implementation of the scheme at the transmitter end will be considered in our future enhancements efforts.

The upper bound of the reservation scheme is determined by the maximum combination of the number of data channels and the number of the data flows which offers better performance. The number of data flows should constitute up to seventy-five percent of the number of data channels. When the number of data flows is allowed to increase beyond the seventy-five percent threshold, the performance of the scheme will degrade significantly. This threshold is expected to increase beyond this point when the proposed scheme is implemented both at the receiver and at the transmitter.

6 Future Work

We are currently investigating how we can improve the performance of the proposed RTS based scheme. The implementation of the scheme is being revisited to ensure that it is a bit more scalable. We will also implement fully our proposed cyclical scheduling algorithm and evaluate its performance with and without the proposed data channel access scheme. However the channel switching technique will be included. The upper bounds will be determined in each case and in other possible approaches that would offer better network performance.

The data channel reservation and access scheme will be implemented at the transmitting terminal to improve the performance of the scheme. The performance of the scheme is expected to increase beyond the upper bound which was identified in this work, when the transmitting terminal is considered. The future work will be an incremental effort to the work done in this paper and will be evaluated in the same environment.

7 Conclusion

The paper demonstrated the efficiency and the scalability of the channel switching delay technique. The discussed results show that the performance of the network did improve with the increase in the size of the network. The efficiency of the control channel increases as the network load increases or when the number of data channels is increased. However, when the control channel approaches its saturation point, the network performance will be degraded. The upper bound should be determined to identify both the optimum maximum number of data channels and the optimum largest size of the network that will render itself to best network performance.

The performance of the data channel reservation and access scheme is a function of network size. Its performance is reasonable when the seventy-five percent threshold is not exceeded. The number of data channels should always be more than the number of data flows for optimal performance. This threshold was identified as the upper bound of the data channel reservation and access scheme. Possible ways of improving the performance of the system will be explored in future. One possible technique of improving the proposed scheme is to extend it to the transmitting terminal. The scheme was only considered for the receiving terminal in this paper.

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