

On-demand channel switching for multi-channel wireless MAC protocols

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Abstract – We propose and analyze the on-demand switching (ODC), a broadcast-based medium access control (MAC) protocol for ad-hoc wireless networks with multiple channels and a single half-duplex transceiver at each host. The ODC performs an on-demand, dynamic, channel selection based on the traffic conditions of the channels and communication patterns of the participating hosts. A host stays on a channel as long as its traffic share on that channel is above a certain threshold, below which it switches to another channel. It broadcasts its departure and arrival before and after each channel switch, respectively. Hosts keep track of these broadcasts and use them to discover their receivers. The channel selection is thus based on reducing the unnecessary receives, while still being able to send and receive legitimate traffic. It results in increased bandwidth utilization, reduced packet delays, and increased energy savings. We evaluate the performance of the ODC with extensive simulations and compare it with the IEEE 802.11 and another related MAC protocol (MMAC). We found that the flow distribution and traffic among hosts have a great impact on its performance. For example, in *one-to-one schemes* with heavy load traffic, there is an up to 180% increase in the aggregate throughput compared to the IEEE 802.11, and a 15-35% increase compared to the MMAC. On the other hand, *star* or *clique* flow distributions tend to favor the IEEE 802.11 over the ODC and MMAC.

I. Introduction

The IEEE 802.11 [1] has been widely deployed to provide wireless LAN access. Its MAC protocol is responsible for coordinating access to the shared radio channel. The IEEE 802.11 employs a CSMA-CA based approach along with virtual carrier sensing and channel reservation techniques. In CSMA-CA, the channel is always sensed before any transmission. If the channel is sensed busy, the transmitter waits for it to become idle and goes through a random back-off period before retrying. The random back-off period ensures fairness among transmitting hosts and also reduces the probability of collisions. In addition, transmitting and receiving hosts exchange *request-to-send* (RTS) and *clear-to-send* (CTS) control frames to reserve the channel before transmitting data packets. This effectively performs a virtual carrier sensing at the receiver. Successful exchange of these control frames also reserves the channel temporarily for the data transmission. Although, the IEEE 802.11 standard provides multiple channels, its MAC layer is designed for sharing a single channel. It performs well under low-load conditions, but under heavy-load conditions, it causes bandwidth under-utilization due to collisions and back-offs. These problems motivate the spatial reuse of the wireless medium. Transmission power control, directional antennae, and multiple channels are the most popular techniques for spatial reuse.

We propose the On-demand channel switching for multi-channel wireless MAC (ODC), a modification to the IEEE 802.11 MAC protocol for multi-channel wireless networks. It allows hosts with a single transceiver to utilize multiple channels by *dynamically* switching from one channel to another. The decision of a host to switch is based on the *traffic conditions* of the channels, its *communication pattern* with other hosts, and its own *bandwidth utilization*. A host performs passive measurements to estimate the traffic conditions and its traffic share. It remains on a channel as long as its traffic share exceeds a certain threshold, below which it switches to another channel. In addition, a simple announcement protocol that requires the hosts to announce their departure and arrival at a channel enables hosts to discover each other. The ODC enables multiple parallel communications

on different channels, which can increase the throughput and reduce collisions, back-off periods, and unnecessary traffic. This can have a dominant impact on the energy consumed by wireless network interfaces.

We analyzed the performance of the ODC via simulations and compared it with the IEEE 802.11 and another multi-channel MAC protocol, the MMAC [4]. Depending on the communication pattern of the hosts, their performance can vary dramatically. We distinguish various communication patterns based on the traffic model and flow distribution among hosts to simulate networks that could potentially use such protocols. For example, one-to-one flow distributions (in which each host is involved in a single flow, either as a source or destination, at a given time) are good candidates for multi-channel protocols, whereas star- and clique-like patterns suit single channel protocols. In the one-to-one case, the ODC exhibits an up to 180% increase in the aggregate throughput compared to the IEEE 802.11 and a 15-35% increase compared to the MMAC at peak load. On the other hand, star and clique schemes tend to favor the IEEE 802.11, although the difference in their performance is less prominent.

The rest of the paper is organized as follows. Section II discusses related work on multi-channel MAC protocols and Section III describes the ODC. We present the simulation models and performance analysis results in Sections IV and V, respectively. Section VI summarizes our main conclusions and future work plans.

II. Related work

Several researchers have proposed modifications on the IEEE 802.11 MAC protocol to use multiple channels [5,6,7]. We classify these approaches into different categories depending on the channel assignment and usage, and the availability of multiple transceivers. We distinguish two main approaches regarding the classification based on the channel assignment. The first dedicates a channel for control packets and uses the remaining channels for data packets, whereas the latter treats all channels identically. Based on the availability of multiple transceivers, there are two main trends, namely, the multiple-transceivers with one per channel, and the use of a common transceiver for all channels. Unlike the multi-transceiver case, the common transceiver operates on a single channel at any given point of time. Recently, manufacturers, such as Engim [10] and D-Link [11], have launched access points (AP) that use multiple channels simultaneously and claim to provide high bandwidth wireless networks. In the following paragraphs, we briefly discuss these multiple-channel MAC protocols and their main results. Table 1 summarizes their classification.

Li *et al.* [5] assume that each node has a single half-duplex transceiver and that the number of available channels is the same as the number of nodes in the network. One of the channels is reserved as the common access control channel and all others are used as traffic channels. The traffic channel reservations for data packet transmissions take place on the control channel through RTS/CTS exchanges. They analyzed the performance of the modified IEEE 802.11 by simulating two network topologies, namely, the line and grid topologies. In the line topology, all nodes are in a single straight line, whereas in the grid topology, nodes are placed at the corners of a grid with hexagonal cells. Compared with the per-node throughput of the single-channel case, there is an increase of 47.8% in line, and 139% to 163% in grid topologies. The end-to-end delay improves marginally for line networks but becomes significant for grid networks.

Research/protocol	Reserved control channel?	Num. of transceivers	Channel selection
Li <i>et al.</i> [5]	Yes	Single	Explicit negotiation
DPC [6]	Yes	Multiple	Explicit negotiation
Nasipuri <i>et al.</i> [7]	No	Multiple	<i>Soft channel reservation</i> (last used channel), Random
RBCS [8]	Yes	Multiple	Explicit negotiation based on interference at receiver
Chaudhuri <i>et al.</i> [9]	No	Single	<i>Home channel</i> (default based on MAC address)
MMAC [4]	Yes	Single	Explicit negotiation, Least selected channel, Random
ODC	No	Single	Arrival and departure broadcasts, Cyclic

Table 1: Classification of different multiple-channel MAC protocols

The dynamic private channel protocol (DPC) [6] assumes hosts with multiple transceivers and thus capable of accessing multiple channels at the same time. Each host has as many transceivers as the number of channels. Like [5], one channel is reserved as the control channel, on which potential senders and receivers negotiate the channel they will use for their communication from. The RTS and *reply-to-RTS* (RRTS) exchange happens on the control channel, whereas the CTS and data/ACK exchanges on the traffic channels. Since all hosts listens to the control channel continuously, they know the status of all channels in their transmission range. Their simulations show that the channel utilization, *i.e.*, ratio of throughput to offered load, increases as the number of channels increases up to 4, but drops beyond 4 channels. This performance degradation is due to the blocking of flows that occurs when a sender and receiver have already agreed to use different channels with other hosts.

Nasipuri *et al.* [7] propose a protocol where each host can concurrently listen to each channel. They introduce the concept of *soft channel reservation*, where a transmitter tries to reuse the channel of its last successful data transmission. They simulate the protocol with soft channel reservation and random channel assignment. They consider the single-user and multi-user scenarios. In single-user, hosts receive only one packet at a time, while in multi-user, hosts receive multiple packets at the same time, each on a different channel. They show that the throughput is significantly higher in the multi-user case and the soft channel reservation performs better than the random channel selection. However, a large number of channels causes an unacceptably high transmission time.

Jain *et al.* [8] propose the *receiver-based channel selection* (RBCS). Like [5], they have a control channel for channel negotiation using RTS/CTS exchange, and multiple data channels for data and ACK frames. The clearest channel is chosen based on the interference power sensed at the receiver. They assume that hosts can carrier sense on all the channels for incoming transmissions. However, at a given time, only one packet can be transmitted on any channel. Their simulations show up to 50% improvement in throughput over the IEEE 802.11 for stationary networks. The improvement is more significant under heavy load conditions, when the contention for channels is high. In mobile networks, they observe higher average packet delays.

Chaudhuri *et al.* [9] propose a simple rendezvous-based protocol in which each host is associated with a particular channel, *i.e.*, its *home channel*, based on its MAC address. Every host waits for all incoming traffic on this home channel. A transmitting host switches temporarily to their receiver's home channel, and returns to its own home channel after completing the transmission. They show that the proportional throughput gain of their protocol *vs.* the IEEE 802.11 decreases with the increase in the ratio of number of transmitting hosts to total hosts.

The MMAC, proposed by Vaidya *et al.* [4], most closely relates to our work. They use the *ad-hoc traffic indication message* (ATIM) window and a control channel for channel negotiation. Each host maintains a *preferred channel list* (PCL) with a high, medium, or low preference attached to every channel. At the start of an ATIM window, all hosts switch to the common control channel. During the ATIM window, senders and receivers negotiate channels using a three-way handshake messaging that indicates also their respective PCLs. At the end of an ATIM window, all hosts switch to their respective selected channel and begin normal RTS-CTS-data-ACK cycles for data transmission. The control channel is also used for data transmission outside the ATIM window. They show a significant improvement over the IEEE 802.11, both in terms of aggregate throughput and average packet delay. However, the MMAC favors scenarios where hosts are involved in only one flow at a time. When hosts are involved in multiple flows, MMAC performs poorly due to the *head of line blocking* problem. This occurs when a sender cannot transmit to a receiver because they are on different channels.

Compared to these approaches, the ODC assumes all channels to be identical in all respects, with no notion of a control channel. In addition, our protocol does not require multiple transceivers or any other specialized hardware. It has been designed for hosts equipped with the most commercially viable wireless network interfaces, which have a single half-duplex transceiver capable of either receiving or transmitting on a single channel at a time. Section V closely compares the ODC with the IEEE 802.11 and MMAC.

III. ODC protocol description

The ODC allows a host to dynamically switch to different channels depending on their traffic condition, its communication pattern and bandwidth utilization at its current channel. Unlike MMAC, we do not assume that channel switch occurs instantaneously. Because of the time and energy overhead associated to channel switch, we try to reduce the number of channel switches. A host remains on its current channel until its condition becomes unacceptable or a potential receiver is on a different channel. In either case, the host switches to an appropriately selected channel after broadcasting its departure announcement. After the channel switch, it broadcasts its arrival announcement on its new channel. Following sections describe the various parts of the protocol in detail.

A. Message types

The ODC introduces two new messages to the existing IEEE 802.11 control messages to assist in host discovery, namely the departure (DEP) and arrival (ARR) announcements. Their destination address is the MAC broadcast address. The DEP message also includes the MAC address of the potential receiver. A host that plans to send some data packets, first broadcasts a DEP message, in which, it specifies the MAC address of the receiver. This MAC address field remains empty when a host broadcasts DEP to indicate that it plans to switch channels for reasons other than to communicate with a host. When a host receives a DEP broadcast in which the receiver field matches its own MAC address, it learns that the source is switching to a new channel to communicate with it. The receiver then switches channel to follow the source.

The ARR message summarizes the traffic conditions that the sender observes on its previous channel during

the last channel observation window (T_{ch}). It includes the total number of bytes transmitted, received, and overheard, and total number of hosts observed on that channel. It also indicates the duration of these observations. The overheard traffic of a host is the one for which it is neither the source nor the destination. The information included in the ARR can give a rough estimate of the traffic rate in that channel during that time period.

B. Traffic entries of local hosts

Each time a host receives an ARR message from a host (e.g., host h), it maintains a traffic history of the sender (h)'s last channel c . More specifically, the host logs the entry $\langle c, r, t \rangle$, where c is the host h 's last channel, r the traffic rate estimated from the information included in that announcement, and t the time when it was received.

C. Host discovery

Each participating host maintains a *channel vector*, in which it records the current channel of all other hosts. Any node that receives a DEP packet records the destination channel field as the current channel of the sender of the packet. Any node that receives an ARR packet records its own channel as the current channel of the sender of the packet. Whenever a host needs to send data, it looks up the destination's current channel in its channel vector, and switches to that channel, if required. A channel vector is not always complete or accurate. A host may not receive all the ARR and DEP due to either packet loss or announcements made on different channels.

D. Traffic estimation in different channels

The traffic estimation is based on ARR announcements and observations of the local host on the traffic of its current channel. Each host locally maintains a *channel history* of all channels and updates it upon the receipt of ARR broadcasts. Specifically, a host records the traffic rate from each ARR message that was received during the last channel history window (H_{ch}). Moreover, each host counts the total number of transmitted, received, and overheard bytes (B_{total}), total number of transmitted and received bytes (B_{trrecv}), and number of hosts on its current channel (N_{hosts}) during the last T_{ch} s. A host also records an entry for the current channel using these measurements. The ODC treats these entries in the same manner as the traffic entries from the ARR announcements. Based on these records, it estimates *the mean traffic rate* on each channel, which is the average of all traffic rates as recorded in the channel history.

E. Channel switching process

The switching process at a local host is triggered each time the host intends to transmit a data packet or has overheard a packet. Before each packet transmission, the sender looks up the channel of the receiver in its channel vector. If it differs from its own current channel, it decides to switch to that channel. The sender, then, sends an RTS to the receiver. After each RTS, the sender waits for CTS from the receiver. If after R_1 RTS retransmissions, it has not received a CTS message from the receiver, the sender switches to the next channel. Similarly, on the new channel, if after R_2 RTS broadcasts, the sender still has not received any CTS from the receiver, it switches to the

next channel. There, it rebroadcasts at most R_3 RTS messages. In the case of no CTS response, the sender drops the DATA packet and switches to its original channel. By next channel, we mean the next channel in cyclic order, *i.e.*, $(\text{current channel} + 1) \bmod N_{\text{ch}}$, where N_{ch} is the number of channels.

Whenever a host overhears a packet, it checks the following conditions in this order. Only when all of them are satisfied, the host decides to switch to its next channel.

1. To prevent from frequent channel switches, the ODC requires hosts to remain continuously on the same channel for *at least* T_{ch} s.
2. There has been at least T_{ch} s since the last time these conditions were checked. If this condition is true, the host sets its arrival time on its current channel to the current time. It also updates the channel history of its current channel with all the traffic observations during the last T_{ch} time window.
3. The time since its last arrival on the new channel is at least $(N_{\text{ch}} + 1) * T_{\text{ch}}$ s. This condition prevents rapid channel scans, when all channels are equally loaded.
4. To prevent receivers from unnecessary channel switches, when they have a fair share of traffic on their current channel, the ODC computes the *traffic share* S_{traffic} on its current channel. It considers the switch only when it is less than S_{thresh} .

$$S_{\text{traffic}} = \frac{B_{\text{trrxrev}}}{2 * B_{\text{total}} / N_{\text{hosts}}}$$

5. The estimated traffic rate of the next channel is at least G_{thresh} % less than the estimated traffic rate on the current channel. As mentioned earlier, each host maintains entries with traffic related information for each channel in its channel history. To estimate the traffic of the next channel, it considers all such entries regarding that channel received during the last H_{ch} s.

When a host decides to switch channels, it broadcasts a DEP announcement at some randomly selected time during the next contention window. After the DEP broadcast, the host immediately switches to the new channel and broadcasts an ARR announcement at some randomly selected time during the next contention window.

IV. Simulation models

We used the ns-2 [2] network simulator with the CMU wireless extension [3] and simulated four scenarios as representatives of different classes of future ad-hoc wireless network applications. These classes are parameterized based on traffic characteristics and flow distribution among hosts. More specifically, we consider a one-to-one scheme with constant bit rate (CBR) traffic, a one-to-one scheme with simulated speech traffic, a star scheme with CBR traffic simulating a sensor or personal area network, and a clique with extreme-value on/off traffic simulating a game (Figure 1).

We use 3 non-overlapping channels of 1 Mbps each, the two-ray ground radio propagation model, and Ad-hoc On-Demand Distance Vector (AODV) routing protocol. The nodes simulate the participant hosts and were placed randomly with a uniform distribution within a 100mx100m grid. They remained stationary throughout the simulations. Each simulation run lasts for 600 seconds. For the performance analysis plots, each data point is an

average of 30 runs. We varied the number of nodes, types of traffic generators, and packet rate to study the performance of the ODC under different traffic load conditions. Table 2 summarizes the simulation parameters.

For the aggregate throughput and average packet delay, we only use the successfully delivered packets. These values represent the overall network throughput and delay when all nodes and channels are considered. Efficiency index is computed by taking the ratio of data traffic and total traffic, on all channels combined for the entire simulation period. Since the IEEE 802.11 uses a single channel, its simulation results show the aggregate throughput obtained using a single channel. On the other hand, the ODC and MMAC use N_{ch} channels and hence their performance results correspond to a throughput aggregated over all N_{ch} channels. We discuss all the scenarios in more detail in the following subsections.

Parameter	Value	Parameter	Value
Number of nodes	2-32	Number of simulations	30
Node placement grid	100 m * 100 m	Simulation duration	600 s
Node placement pattern	Random	Traffic generation start time	0-1 s
Node mobility	Stationary	Traffic generation end time	600 s
Radio propagation model	Two-ray ground	Channel switching time (T_{switch})	100 μ s
Radio transmission range	250 m	Traffic share threshold (S_{thresh})	80 %
Ad-hoc routing protocol	AODV	Traffic gain threshold (G_{thresh})	20 %
Number of channels (N_{ch})	3	Channel history window (H_{ch})	30 s
Bandwidth per channel (B_{ch})	1 Mbps	Channel traffic window (T_{ch})	3 s
		RTS retransmission limits (R_1, R_2, R_3)	7, 4, 3

Table 2: Simulation parameters and their value

A. One-to-one flow distribution with CBR traffic

In one-to-one, each node is involved in a single flow, either as a source or destination. Half the nodes are selected as sources and the other half as destinations with one-to-one mapping between sources and destinations. Each source generates CBR traffic with a fixed packet size of 512B. We vary the number of nodes from 2 to 32 (in powers of 2), and packet arrival rate (pps) on each flow from 1 pps to 512 pps.

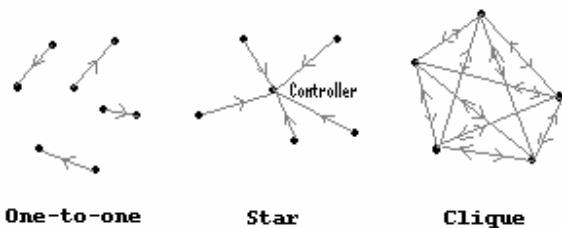


Figure 1: Distribution of flows across hosts

	Location	Scale
Packet size	120	36
Packet inter-arrival time	0.055	0.006

Table 3: Extreme-value parameters for game traffic

B. One-to-one flow distribution with simulated speech traffic

Each traffic source generates simulated speech traffic. The speech traffic follows an exponential distribution with alternating ON (talk spurt) and OFF (silence) periods of mean lengths 1.004s and 1.587s, respectively [13]. During the talk spurts, packets of fixed size, 512B are generated at a constant bit-rate. We vary the number of nodes from 2 to 32 (in powers of 2), and the packet arrival rate during talk spurts on each flow from 1 pps to 512 pps.

C. Star flow distribution with CBR traffic and central controller as in sensor or personal area networks

In star schemes, the central node is treated as a controller in a wireless LAN. All other nodes have a flow to the controller. The traffic sources on these nodes generate CBR traffic. We vary the number of nodes from 2 to 16 in powers of 2, and the packet arrival rates for each flow from 1 pps to 256 pps. This could correspond to a sensor or a personal network; the central node is a controller or a server and other nodes are sensors or devices of the personal area network.

D. Clique flow distribution with extreme-value on/off traffic as in peer-to-peer games

We also attempt to simulate a peer-to-peer game traffic where every player communicates with every other (e.g., the *Age of Empires*). Farber [12] shows that the traffic between players in most common network games follows an *extreme-value distribution* [14], both in the packet size and their inter-arrival time. Each node corresponds to a player. We vary the number of nodes from 2 to 8. Every node has a flow to every other node and its traffic follows the extreme-value distribution (Table 3 shows its parameters).

V. Performance analysis via simulations

A general observation is that one-to-one flow distribution patterns are good candidates for multi-channel protocols, whereas star- and clique-like patterns do not perform well. In one-to-one, pairs of sender and receiver can be evenly divided among the available channels, thus reducing the channel switches. Using the ODC and MMAC, the throughput is approximately 2.5-3 times of that of the IEEE 802.11, and the packet delays are relatively much smaller (Figures 2 and 3). On the other hand, star patterns follow an opposite trend (Figure 4). There, all hosts communicate with a central host. The ODC would perform better if all hosts stayed on the same channel. Multi-channel support and channel switches do not particularly help much. The IEEE 802.11 performs better in terms of throughput. In ODC and MMAC, the average packet delay is smaller than in IEEE 802.11, because channel switches reduce collisions on the channel of the central host. Yet, the gain in packet delays does not justify the loss in throughput. With clique-like patterns, channel changes may result in smaller throughput and longer packet delay (Figure 5). We discuss the results in more detail in the following paragraphs. Due to space limitations, we only include the plots for networks with 4, 16, and 32 nodes. The complete set of plots can be found in [15].

One-to-one flow distribution

In one-to-one patterns (Figures 2 and 3), the ODC exhibits 20-25% smaller average packet delay than the MMAC, irrespective of the network size. This is mainly because the MMAC reserves 20ms for the ATIM per beacon (typically 100ms). During an ATIM window, senders and receivers exchange channel negotiation messages and select the channels for data transmission. There is no data exchange during ATIM window. At the end of an ATIM window, all hosts switch to their respective selected channels and continue the data transmission with RTS-CTS-DATA-ACK cycles (for the remaining 80ms interval). This periodic hiatus in data transmission is the primary source of increased packet delays in the MMAC. However, the ODC and MMAC exhibit 65-70%

smaller packet delays compared to the IEEE 802.11. This is due to the use of multiple channels, which reduces collisions and retransmissions.

In terms of throughput, the ODC and MMAC consistently perform better than the IEEE 802.11. This is due to the use of multiple channels, which essentially increases the total bandwidth by as many times as the number of channels. The ODC provides higher aggregate throughput than the MMAC for small and large networks, and comparable aggregate throughput for medium size networks. This happens mainly because the 20ms ATIM window per 100ms beacon interval is too long for small networks. The data transfer takes place only during the remaining 80ms, thereby restricting throughput to 80% of the maximum achievable. Unlike the MMAC, the ODC does not have any concept of ATIM window or beacon interval. The timeline is contiguous, and data transfer as well as channel switches can happen anytime. In small-size networks (2-6 nodes), hosts can easily find each other and stay on their channels. This is particularly true for scenarios with one-to-one topology where each host is involved in only a single flow. In the two-node case, the ODC provides the same throughput as the IEEE 802.11 but higher than the MMAC. We see similar trends in 4-node networks (Figures 2 and 3).

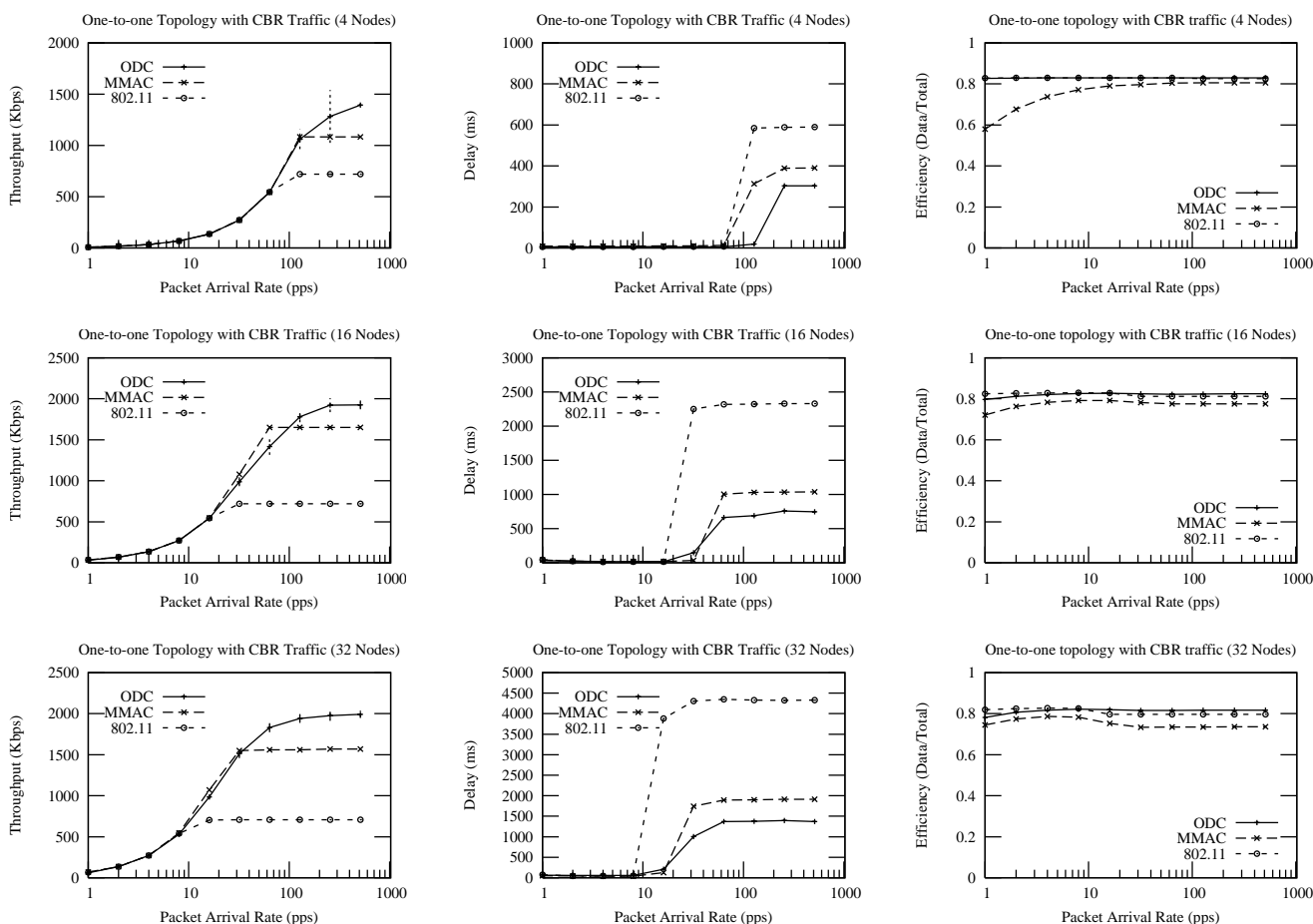


Figure 2: Aggregate throughput, average packet delay and efficiency for one-to-one flow distribution with CBR traffic

Each channel negotiation during an ATIM window of the MMAC involves a three-way handshake to decide the channel. Each handshake cycle takes from 1-2.5 ms on average, including the interval between the last

message of one cycle and the first message of the next cycle. Observations from the simulation traces show that the number of three-way handshakes per ATIM window is 8-16, with an average of 11. On average 11 communicating pairs are able to negotiate channels during the ATIM window. For a medium-size network (8 to 16 nodes), the ATIM window in MMAC is just sufficient for most communicating pairs of nodes to negotiate channels. Whereas, the ODC does not have any channel negotiation and senders and receivers can end up being on different channels. With such network sizes, the ODC is expected to perform comparable to the MMAC. In medium size networks, the ODC and MMAC perform similarly with respect to throughput (Figure 2 and 3).

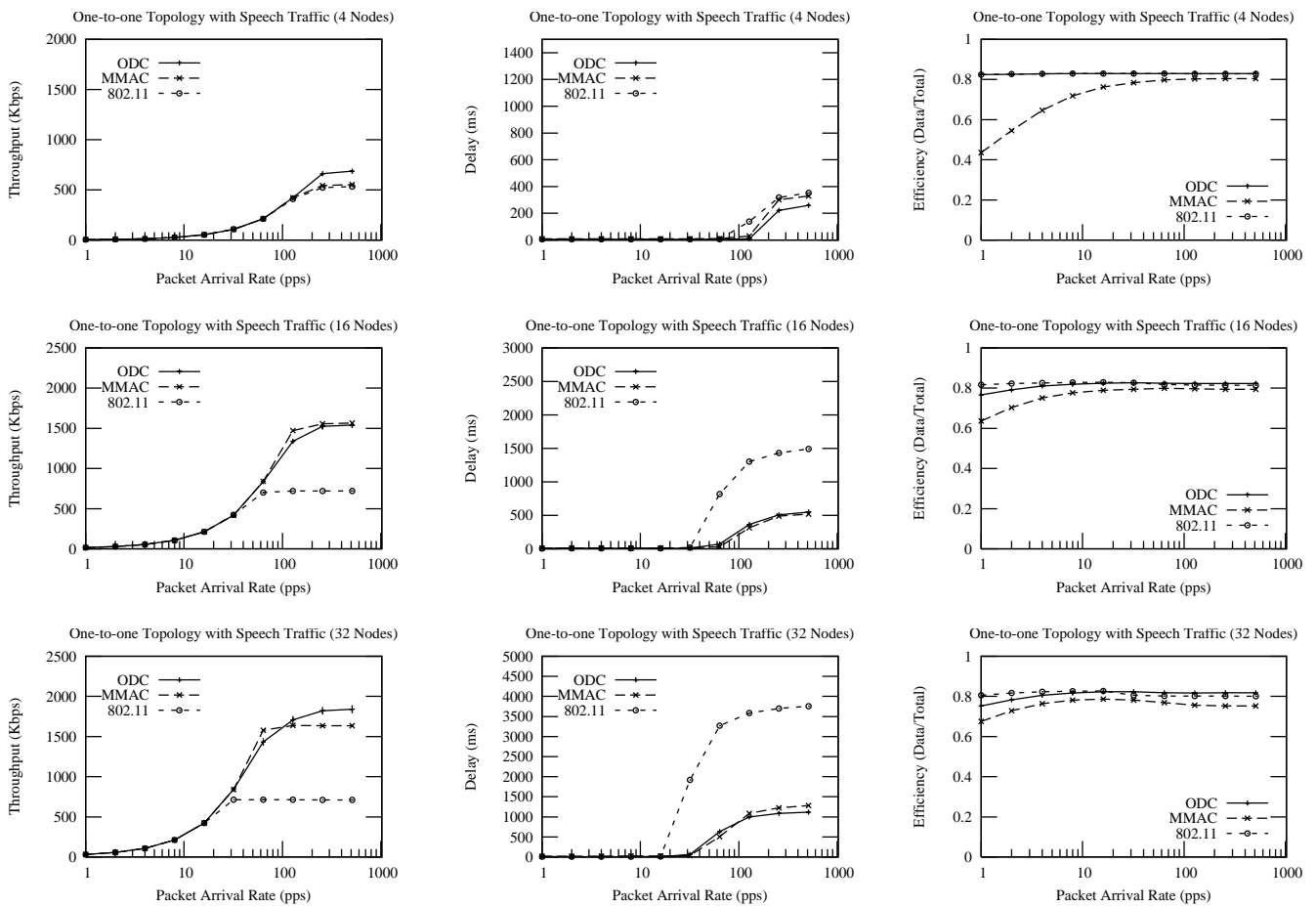


Figure 3: Aggregate throughput, average packet delay and efficiency index for one-to-one flow distribution with speech traffic

In larger networks (with 32 nodes or more), the ODC performs better than the MMAC, because unlike in MMAC, nodes in ODC do not reset channel information of other nodes. The 20ms ATIM window of the MMAC is not sufficient for all communicating pairs to negotiate channels. In addition, there are more communicating pairs attempting to negotiate channels than that can be accommodated, which results in more collisions and greater delays. As a result, nodes unable to negotiate channels with their peers switch to randomly selected channels at the end of ATIM window. In ODC, nodes maintain channel information about their peers and nodes do not randomly switch channels. As a result, the ODC exhibits higher aggregate throughput than the MMAC.

To estimate the protocol overhead, we define efficiency index (μ) as the ratio between total data traffic and total traffic (including the control messages) on all channels during the entire simulation period. We contend that $(1 - \mu)$ gives a close estimate of protocol overhead in terms unnecessary network traffic. The higher the protocol overhead, the higher is the wasted bandwidth and energy consumption. The ODC approximates the IEEE 802.11; whereas the MMAC has high protocol overhead, especially at low packet transmission rates (rightmost Figures 2 and 3). Thus the ODC would be more energy efficient than the MMAC in one-to-one network scenarios.

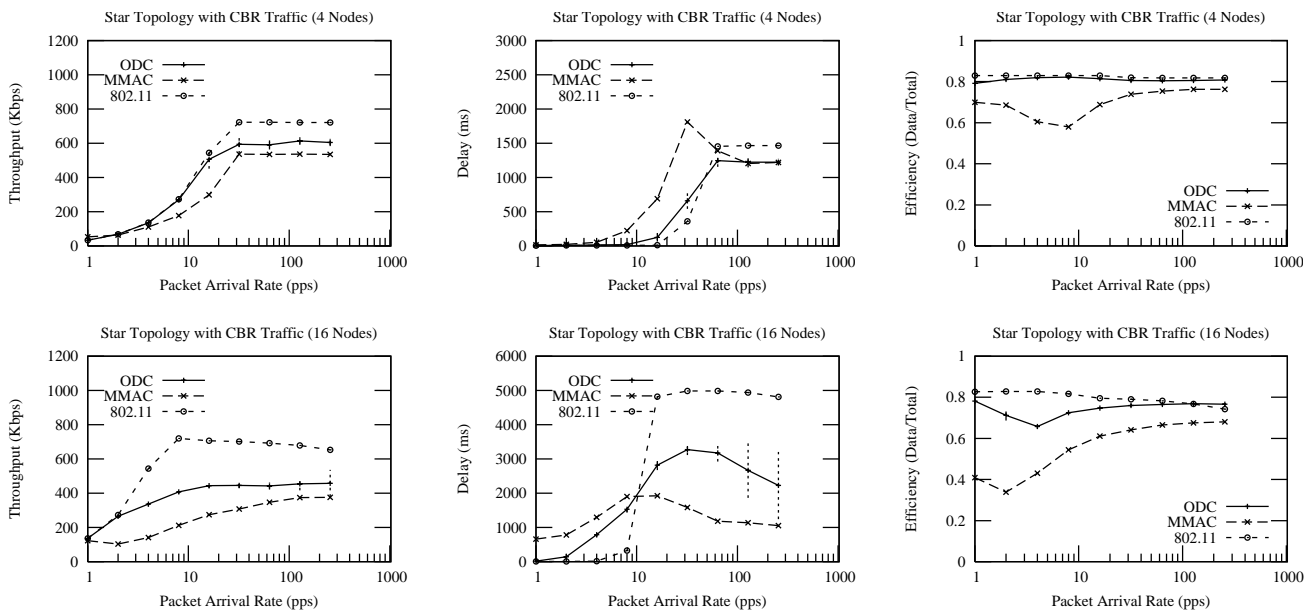


Figure 4: Aggregate throughput, average packet delay and efficiency index for star flow distribution with CBR traffic

Star and clique flow distribution patterns

To analyze the worst-case performance of the ODC, we have simulated it for star and clique network topologies. Figures 4 and 5 show the performance of ODC, MMAC, and IEEE802.11 with respect to throughput, packet delay, and protocol efficiency. As expected, single channel protocol like the IEEE 802.11 provide the maximum throughput in these scenarios. Since all nodes contend for the medium on the same channel, packet delays are higher using the IEEE 802.11.

In the star topology, we observe that the ODC provides higher throughput than the MMAC for all network sizes. This happens because in the ODC all nodes try to stay on the same channel as the central node. Whereas, in the MMAC nodes switch to other channels if they are not able to negotiate channels with the central node during the ATIM window. In addition, 20ms ATIM window causes further decrease in throughput in the MMAC. Average packet delay in case of the MMAC is better than that in the ODC because there are fewer collisions due to fewer transmitting nodes on the same channel as the central node compared to the ODC. The efficiency index plots show that the ODC introduces a small additional protocol overhead over the IEEE 802.11. The MMAC exhibits higher protocol overhead than the ODC and IEEE 802.11.

In clique schemes, the ODC and MMAC perform similarly and the IEEE802.11 outperforms them in terms of aggregate throughput and average packet delay (Figure 5).

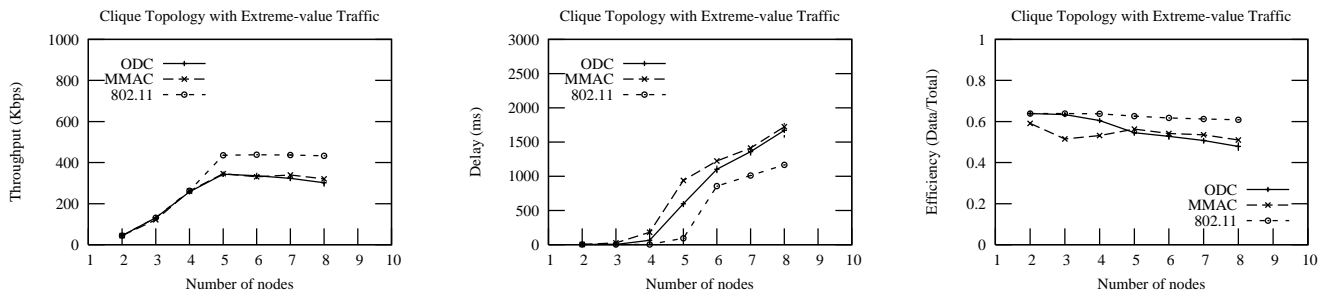


Figure 5: Aggregate throughput, average packet delay and efficiency index for clique flow distribution with extreme-value traffic

VI. Conclusions and future work

As the performance analysis indicates, communication patterns, such as traffic characteristics and flow distribution affects the performance of the protocol. Based on the characteristics of the system to be deployed, availability of transceivers, channel switching overhead, its expected communication patterns and requirements (such as delay and energy constraints), a designer can choose a certain MAC protocol over another. To be able to have a reliable performance analysis, it is critical to use realistic traffic and communication models at least for representative applications and environments. We are very interested in such issues and pursue several projects that focus on characterizing the wireless access in different environments.

Channel switches in ODC take place on a per packet basis. We plan to investigate how hosts could make a more informed channel selection. One approach is the hosts to look ahead in the packet queue and rearrange the packets, before deciding to switch channels.

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