Analytical Model of IEEE 802.11s MCCA-based Streaming in the Presence of Noise*

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Abstract

In the paper, we present an analytical study of multimedia stream transmission with the reservation-based channel access method called MCCA in IEEE 802.11s mesh networks. Various aspects of MCCA have been already studied under the assumption that the reservation guarantees successful transmission, no retries are needed and the period of reserved times is equal to the inter-arrival time of the input stream. However, recent papers reveal the fact that two-hop advertisement of reservations, as adopted in MCCA, fails to completely defeat the interference affecting transmissions in addition to random noise. To keep the packet loss ratio (PLR) acceptable for a stream, period of reserved times may be shortened to allow packet retries. However, a packet of a stream is usually discarded when the packet delay reaches its threshold, making its contribution to the PLR. Also, additional reservations is a burden. In this paper, we propose an analytical model to find the maximal period of reserved times to keep the packet loss ratio and delay below thresholds, given the input stream bit rate and packet error rate.

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1 Introduction

To keep pace with consumer needs, IEEE 802.11 has recently shown big progress in providing support for robust voice and video streaming. Task Group "s" developed
MCCA [6] medium access method based on prior periodic reservations, which may be efficiently used to meet QoS demands for voice and video streaming in IEEE 802.11s mesh networks. Within its reservations characterized by the duration and periodicity, a station (STA) gets access to the medium with lower contention than would otherwise be possible, providing a regular traffic such as voice and video stream transmission with parameterized QoS.

Since MCCA[1] access method was introduced in 2006 in one of the proposals to IEEE 802.11 Task Group "s", see [10], a number of papers, e.g. [3, 5], were published by MCCA authors Hiertz et al. following the method evolution in the Task Group. The papers describe MCCA in detail and prove the concept by comparing MCCA with EDCA based on preliminary simulation results obtained with WRAP2 simulation environment in a number of scenarios.

IEEE 802.11s draft does not require that all mesh STAs support MCCA, so some STAs may ignore reservations made by others. Two attempts were made to evaluate how MCCA-incapable STAs affect MCCA-capable STAs with the help of OPNET [9] and ns-2 [8] simulation tools and to modify the access method for MCCA-capable STAs to ensure that they get channel for reserved time. In particular, [1] proposes to allow a mesh STA to continue accessing the medium even *after the end* of its reserved period, to complete the delayed transmission caused by non-MCCA traffic. In turn, [7] proposes to allow a mesh STA preemptive access to the medium *before the beginning* of its reservation. Both proposed modifications, besides violating original MCCA rules and IEEE 802.11 philosophy of contention, make the MCCA traffic exposed to interference from hidden STAs as the transmissions outside reservations are not advertised and experience same interference as with random access.

In IEEE 802.11 performance evaluation literature, hidden STAs are usually defined as those which are two-hop neighbors for the transmitter and one-hop neighbors for the receiver. MCCA counteracts the interference coming from hidden STAs by advertising reservation periods for the two-hop neighborhood of both the transmitter and receiver. Unfortunately, the interference also comes from outside the two-hop neighborhood and affects badly

[1]In early IEEE 802.11s drafts, MCCA access method was called Mesh Deterministic Access (MDA). Though some referred papers use MDA, we use the present name everywhere in this paper.

the MCCA performance, as shown by Cicconetti et al. in [2]. The paper addresses the problem of placing the reservations within the DTIM interval[2] and proposes a reservation relocation algorithm to find the place within the DTIM interval free from the interference coming from outside the two-hop neighborhood. If such interference comes from other MCCA traffic, i.e. it comes on regular basis, the proposed algorithm is quite efficient indeed, as proved by simulation results obtained with ns-2. If EDCA traffic coexists in the network with MCCA traffic, interference cannot be 100% escaped and packets are transmitted with non-zero error rate in any place of DTIM interval. Moreover, transmissions may be corrupted due to random noise inherent in wireless networks.

Consequently, though advertised in the two-hop neighborhood in advanced, transmissions within MCCA reservations may fail and retransmissions may be needed to meet QoS demand on packet loss ratio (PLR). On the other hand, the packet delay must be kept below a threshold, otherwise the retransmissions cannot prevent the packet from being discarded. So, the key issue of MCCA, which is not investigated yet, is optimal choice of the reservation period to consume minimal channel resources and keep both the PLR and delay below thresholds, in the presence of random noise and interference.

In this short paper, we present a simple analytical model predicting the average PLR for constant bit rate (CBR) voice stream transmitted over a noisy channel between two MCCA-capable nodes which set up a reservation, given that a packet is discarded when its delay reaches the threshold value. Analysis of the modeling results‘ reveals the optimal choice of reservation period.

Though a path in a mesh network is often multi-hop, we believe that the single-hop case model is a building block laying the foundation for further research. In the next two sections, the model and numerical analysis are presented. Discussion on further steps concludes the paper.

2 Model Description

The input stream is CBR with fixed-size packets and interarrival time t^*_λ. QoS demands are characterized by maximal delay D_{QoS} and maximal packet loss ratio L_{QoS}. Transmission errors happen with fixed probability q. We suppose

[2] Due to short paper size limitation, here and further in the paper we do not introduce IEEE 802.11 basic terminology assuming it is well-known to majority of readers thanks to hundreds of papers published during the last decade.

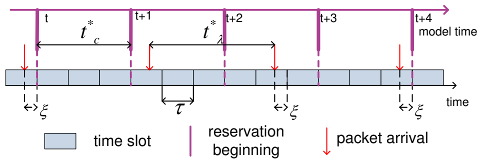

Figure 1: Markov process time instances at the scale of slots.

transmissions are immediately acknowledged and not bounded by any retry limit, so a packet may only be lost when the delay reaches a threshold.

To transmit the stream, MCCA periodic reservations are set up with period $t_c^* \leq t_\lambda^*$ and duration R equal to the packet transmission time plus acknowledgement transmission time plus interframe spaces. A packet transmission attempt starts at the beginning of a reservation if the packet has spent in the queue no longer than $D = D_{QoS} - R$ time. Otherwise, the packet is discarded and the next packet in the queue (if any) is considered.

Represent t_λ^*/t_c^* as an irreducible fraction t_λ/t_c, where $t_\lambda, t_c \in N$. Further we refer to a time interval of length τ,

$$\tau = \frac{t_\lambda^*}{t_\lambda} = \frac{t_c^*}{t_c},$$

as a slot. Let us divide the continious time scale into slots, so that the beginning of each resevation coincides with the beginning of some slot. The MCCA-based streaming process is represented by a discrete-time unidimensional Markov chain with the time unit equal to t_c slots, so that instances t and $t + 1$ of model time correspond to the beginnings of two consecutive reservations, see Fig. 1.

At each instance t the state of the system is characterized by an integer number $h(t)$. If $h(t) \geq 0$, the queue is not empty and $h(t)$ is the number of whole slots the oldest packet spent in the queue. Since packets arrive periodically, the time ω_j the j^{th} packet from the head of the queue has spent in the queue is $\omega_j = \omega_1 - (j-1) \cdot t_\lambda^*$. If $h(t) < 0$, the queue is empty and $|h(t)|$ equals the time to the next packet arrival, expressed in slots and rounded down.

The minimal value of $h(t)$ equals $t_c - t_\lambda$. It is achieved when a packet arrives into an empty queue exactly at time instance t and it is successfully transmitted with a single attempt.

Let us find the maximal value of $h(t)$. Since the time interval between two packets arrivals contains an integer number of slots τ, the time interval ξ between a packet arrival and the beginning of the next slot is constant for all packets, $0 \leq \xi < \tau$ (see Fig. 1). At any instance t of model time, the oldest packet has spent $h(t) \cdot \tau + \xi$ time in the queue. In order for the packet not to be immediately discarded, this time shall not exceed D. So $h(t) \leq d = \lfloor \frac{D-\xi}{\tau} \rfloor$ and state $h(t) = d$ is achieved when the packet delay reaches D within the slot immediately following the beginning of a reservation.

From a non-negative state $h(t) = i \geq 0$ the system moves either (a) to state $h(t+1) = i - t_\lambda + t_c$ when the oldest packet leaves the queue after a successful transmission or when the maximal delay is reached, i.e. $i + t_c > d$, or (b) to state $h(t+1) = i + t_c$ when the oldest packet remains in the queue because the transmission at time instance t fails and the maximal delay is not reached, i.e. $i + t_c \leq d$.

In a state $h(t) = i < 0$ the queue is empty, so the system skips the reservation at time instance t waiting for a new packet arrival and moves to state $h(t+1) = i + t_c$.

So, the admitted states of the system are those from interval $\{-t_\lambda + t_c, \ldots, d\}$. Let p_i, $i \in \{-t_\lambda + t_c, \ldots, d\}$, be the stationary distribution of the Markov chain. The equations for the stationary probabilities are $p_i = \alpha_i \cdot p_{i-t_c} + \beta_i \cdot p_{i+t_\lambda-t_c}$, where:

$$\alpha_i = \begin{cases} 0, & i < -t_\lambda + 2t_c, \\ q, & t_c \leq i \leq d, \\ 1, & -t_\lambda + 2t_c \leq i < t_c; \end{cases}$$
$$\beta_i = \begin{cases} 0, & i > d - t_\lambda + t_c, \\ 1 - q, & i \leq d - t_\lambda, \\ 1, & d - t_\lambda < i \leq d - t_\lambda + t_c. \end{cases}$$

Also, obviously $\sum_{i=-t_\lambda+t_c}^{d} p_i = 1$. Solving the equation system, we find the stationary probabilities.

Since a packet is dropped with probability q after transmission from any state i such that $i + t_c > d$ and on average t_c/t_λ packets arrive during a model time unit, packet loss ratio equals

$$PLR = q \cdot t_\lambda / t_c \sum_{i=d-t_c+1}^{d} p_i.$$

3 Numerical Results

Fig. 2 plots PLR versus reservation period t_c^*. In the shown case, $t_\lambda^* = 20$ ms which is usual for voice traffic, packet error rate $q = 0.3$, and $\xi = 0$ which is achieved by aligning the first packet arrival time with the beginning of a reservation. When $t_c^* = t_\lambda^*$ the number of reservations is equal to the number of input packets, so PLR, regardless of the value of maximal acceptable

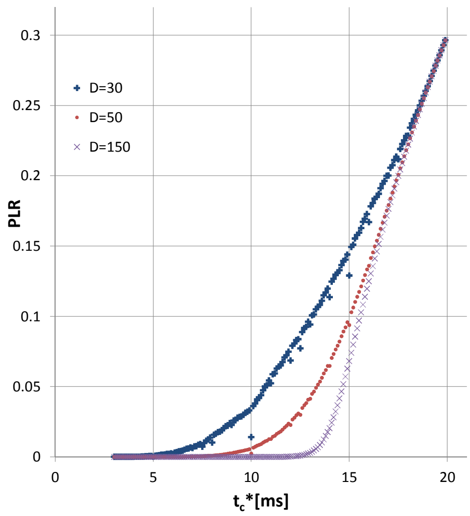

Figure 2: PLR versus t_c^*: $t_\lambda^* = 20$ ms, $q = 0.3$

delay D, equals q. Lower values of t_c^* and higher values of D naturally decrease PLR, as more frequent reservations give additional chance for packet transmission and higher acceptable delay allows packets to take this chance.

An interesting fact is that function PLR(t_c^*) is nonmonotonic at any point because of the following reason. The maximal number of transmission attempts of a packet, which determines PLR, is a discrete quantity equal to $\lfloor \frac{D-\xi}{t_c} \rfloor$. D and ξ are constants, and $t_c = t_c^*/\tau$ where τ is a nonmonotonic function of t_c^* at any point.

In the case shown in Fig. 2 when $\xi = 0$, given t_λ^* and D, an additional packet transmission attempt is available at some particular points of t_c^* comparing with neighboring points, resulting in PLR drop at these particular points. The drop magnitude Δ depends on a number of factors. First, Δ grows with the value of τ. It reaches maximum when t_λ^* contains t_c^* and $\tau = t_c^*$, $t_c = 1$. In this case, a reservation begins within a slot after every packet arrival, every packet arriving in an empty queue gets an additional transmission attempt, and PLR shows considerable drop, e.g. see point $t_c^* = 10$ in Fig. 2. When t_c^* and t_λ^* are coprimes, $\tau = 1$, $t_c = t_c^*$ and only one of t_c packets gets such an additional attempt, resulting in much less considerable PLR drop. Second, Δ is greater for smaller D, as when the maximal number of transmission attempts of a packet is relatively small one additional transmission attempt is more remarkable.

At most points the deviation of PLR from the trend line is negligible and function PLR(t_c^*) looks like monotonic, which allows predicting PLR based on the reservation period. With that, aligning the arrival time of packets with the beginning of reservations advantages lower PLR.

4 Further Work

In [4], authors of MCCA noted that 802.11 enters uncharged territories by developing a mesh networking technology. Indeed, plethora of issues arise with the medium access in a multihop network in the face of interference.

In this short paper, we present a simple analytical model predicting the average PLR for constant bit rate (CBR) voice stream transmitted over a noisy channel between two MCCA-capable nodes. Next steps of this work-in-progress are to extend the model (a) for the multihop case which is not trivial as the stream becomes non-CBR and (b) for the multicast medium access methods, Directed Multicast Service and Groupcast with Retries, recently developed by Task Groups "v" and "aa".

5 Acknowledgements

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