Non-preemptive $\sum_i D$-BMAP$_i$/D/1/K queuing system modeling the frame transmission process over wireless channels

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Abstract. We identify a class of priority queuing systems of G+G/GI/1/K type capable to model the frame transmission process over the wireless channel with correlated losses. To represent arrival process of frames and service process of the wireless channel we use hidden Markov models. Performance evaluation model is then reduced to $\sum_i D$-BMAP$_i$/D/1/K queuing system with non-preemptive priority discipline. The proposed queuing representation allows to capture distributional and autocorrelation properties of the frame service process at the wireless channel. Finally, this model is analyzed for a number of performance parameters of interest.

Keywords: non-preemptive $\sum_i D$-BMAP$_i$/D/1/K queuing system, wireless channels.

1 Introduction

Queuing theory is widely used in performance evaluation of fixed networks. Modeling the information transmission process over the wireless channel is strictly related to its applications. However, early studies did not consider queuing theory as an appropriate tool in wireless domain. We fill this gap proposing a queuing-theoretic model for performance evaluation of frame transmission process over the wireless channel. We identify a set of models that are well-suited for this purpose and outline their properties. We consider $\sum_i D$-BMAP$_i$/D/1/K queuing system with non-preemptive priority discipline as a candidate model and show how it can be used to derive performance parameters of interest.

The rest of the paper is organized as follows. In Section 2 we provide a review of the related work. We introduce our approach in Section 3. Models of the frame arrival and frame error processes are proposed in Sections 4 and 5, respectively. The candidate performance evaluation model of $\sum_i D$-BMAP$_i$/D/1/K type is studied in Section 6. Numerical examples are given in Section 7. Conclusions are drawn in the last section.

2 Related work

To date a number of performance models for frame transmission process over the wireless channel have been proposed. Among others, one have to mention studies of Zorzi and Rao
The approach is inherently theoretical and based on two-states Markovian model of the wireless channel. However, authors used rather simple traffic model that may not always provide adequate representation of the frame arrival process. In [4] Mukhtar et al. proposed an accurate model for performance evaluation of automatic repeat request (ARQ) Type II error concealment procedures at the data-link layer. The solution for steady-state parameters of the system involves estimation of steady-state probabilities of three-dimensional Markov chain. Due to rather limited application field of such processes, there are no efficient algorithms to compute these probabilities. Again, relatively simple model was used to represent the traffic part. In [5], to model frame transmission process at the data-link layer, authors used D-BMAP/PH/1 queuing system with first come first served (FCFS) service discipline, where discrete-time batch Markovian arrival process (D-BMAP) is used to represent frame arrivals. To implicitly capture effects of ARQ error concealment procedures authors assumed that the service of the frame is distributed according to continuous phase-type (PH) distribution. Here, the service time refers to time required to successfully transmit a single frame over the wireless channel. Therefore, service times of frames are assumed to be independent and identically distributed random variables (RV). This assumption does not always hold in practise. As an example, autocorrelation functions (ACF) of two frame error traces of IEEE 802.11b wireless channel are shown in Fig. 1. Lag-1 autocorrelations of both processes are relatively high and statistically significant. Thus, D-BMAP/PH/1 model may produce biased representation of the frame transmission process over wireless channels with strong memory properties. Moreover, an infinite number of waiting positions is not adequate assumption for real systems, especially, for mobile devices where the buffer space is limited.

![ACF of IEEE 802.11b 5.5Mbps and 2Mbps frame error traces.](image)

Fig. 1. ACF of IEEE 802.11b 5.5Mbps and 2Mbps frame error traces.

3 Performance model of the wireless channel

The straightforward way to represent the frame transmission process over the wireless channel is to use $G_A/G_S/1/K$ queuing system, where $G_A$ is the frame arrival process, $G_S$ is the service process of the wireless channel, $K$ is the capacity of the system. It is known that both interarrival times of frames from the traffic sources and transmission times of
frames till successful reception are generally not independent but autocorrelated. This property significantly complicate analysis of $G_A/G_S/1/K$ queuing systems even when both arrival and service processes can be accurately modeled by Markovian processes. Indeed, theoretical background of queuing systems with autocorrelated arrival and service processes is not well-studied. Thus, from computational point of view, such a performance model does not provide significant improvements over other approaches.

Consider now a class of preemptive-repeat priority systems with two Markovian arrival processes. We allow both processes to have arbitrary autocorrelation structures of homogenous Markovian type. Assume that the first arrival process represents the frame arrival process from the traffic source. To provide an adequate representation of unreliable transmission medium, we assume that the second arrival process is the frame error process of the wireless channel. Making this process to be high priority one, and allowing its arrivals to interrupt ongoing service of low priority arrivals, we assure that when an arrival occurs from this process it immediately seizes the server for service, while the ongoing service is interrupted. The frame whose service is interrupted remains in the system and may enter service again only after service completion of the high priority arrival. Such a behavior is interpreted as an incorrect reception of the frame from the traffic source, and the priority discipline is referred to as preemptive-repeat.

To emulate behavior of stop-and-wait ARQ (SW-ARQ) protocol, for such a system we allow an infinite number of retransmission attempts. This assumption seems to be practically appropriate for real wireless channels. For example, for IEEE 802.11b traces considered in previous section we did not observe more than five consecutive errors. We also assume that the feedback channel is perfect. According to this model, the receiver notifies the sender about incorrect reception of the frame during the transmission time of a high priority arrival (error). In addition to reliability of the feedback channel, we also assume that the feedback is immediate, i.e. the source knows about incorrect reception of a frame at the end of the time slot in which this frame was incorrectly received. Since we defined the wireless channel model at the data-link layer, possible forward error correction (FEC) at the data-link layer is implicitly included.

Analysis of queuing systems with priority discipline is still a challenging task. Among others, preemptive-repeat is probably most complicated priority discipline. However, a number of assumptions can be introduced to make the queuing model less complicated. In what follows, we limit our model to discrete-time environment and require each arrival from any arrival process to have a service time of one slot in duration. According to such a system, arrivals occur just before the end of slots. Since there can be at most one arrival from the arrival process representing the frame error process of the wireless channel, these arrivals do not wait for service, enter the service in the beginning of nearest slots, and, if observed in the system, are being served. Taking all these assumptions, it is no longer needed to require priority discipline to be preemptive-repeat. Since all arrivals occur simultaneously in batches, it is sufficient for such a system to have non-preemptive priority discipline.

### 3.1 Contention-free constant bit rate access

When a constant bit rate (CBR) channel is assigned to a mobile terminal during the whole duration of a call, to estimate performance parameters of frame transmission process we
can directly apply $\sum_i GM_i/D/1/K$ queuing system. Such a model provides an adequate representation of time-division multiple access (TDMA) organization of the wireless access. According to TDMA, each source has an unrestricted access to a circuit-switched channel, on which transmission is organized. Thus, there is no data-link layer concurrent traffic competing for resources on this channel, and the only performance degradation stems from unreliable nature of the wireless channel. To quantitatively study the frame transmission process, we have to derive performance parameters of the frame arrival process in $\sum_i GM_i/D/1/K$ queuing system.

4 Traffic model

We D-BMAP as a model of the frame arrival process. The reason is twofold. First of all, it was shown that D-BMAP allows to model quite complex VBR traffic sources. Particularly, in [8] authors used D-BMAP to represent generation process of I-frames at the output of MPEG-1 codec. In [9] D-BMAP was used to model a voice traffic source with silence suppression capabilities and different levels of comfort noise. Klemm et al. [10] developed an algorithm for continuous-time counterpart of D-BMAP to model an arbitrary IP packet arrival process. Secondly, the queuing of D-BMAP is well studied and quite general results have been obtained [11–13]. Thus, usage of D-BMAP provides a required versatility of the modeling environment and allows to preserve analytical tractability.

Consider characteristics of D-BMAP. Assume a discrete-time environment, i.e. time axis is slotted, the slot duration is constant and given by $\Delta$. Let $\{W_A(n), n = 0, 1, \ldots \}$ be D-BMAP. According to it, value of the process is modulated by the discrete-time Markov chain $\{S(n), n = 0, 1, \ldots \}$, $S(n) \in \{1, 2, \ldots, M\}$. Let $D$ be its transition probability matrix. We define D-BMAP as a set of matrices $D(k), k = 0, 1, \ldots$, containing transition probabilities from state to state with $k = 0, 1, \ldots$ arrivals, respectively. Thus, for each pair of states $d_{ij}(k) = \lim_{n \to \infty} Pr\{W_A(n) = k, S(n) = j|S(n-1) = i\}$, $k = 0, 1, \ldots$, are conditional probability functions of D-BMAP. Let then vector $G = (G_1, G_2, \ldots, G_M)$ be the mean vector of D-BMAP, where $G_i = \sum_{j=1}^M \sum_{k=0}^\infty kd_{ij}(k)$, $i = 1, 2, \ldots, M$. The mean process of D-BMAP is defined as $\{G(n), n = 0, 1, \ldots \}$ with $G(n) = G_i$, while the Markov chain is in the state $i$ in the time slot $n$. Its ACF is

$$R_G(i) = \sum_{l,l \neq i} \phi_i \lambda_i^l, \quad i = 1, 2, \ldots, \tag{1}$$

where $\phi_i = \pi(\sum_{k=1}^\infty kD(k))g_i h_i(\sum_{k=1}^\infty kD(k))e$, $\lambda_i$ is the $i^{th}$ eigenvalue of $D$, $g_i$ and $h_i$ are left and right eigenvectors of $D$, and $e$ is the vector of ones of appropriate size. The number of terms composing ACF of the mean process of D-BMAP depends on the number of eigenvalues. Varying the number of states of the modulating Markov chain we vary the number of geometrical terms (here, eigenvalues) composing the ACF.

5 Wireless channel model

A frame error trace is a sequence of successive events of correct and incorrect frame reception. To use theory of stochastic processes, we define frame error trace as a sequence
of RVs. We assume that '1' represents an incorrectly received frame and '0' denotes a correctly received frame. Successive realizations of this RV compose the frame error trace \{W_C(n), n = 0, 1, \ldots \}, \ W_C(n) \in \{0, 1\}. A number of studies suggested that this process can be treated as at least partially covariance stationary ergodic one. Using these properties, one can compute all important statistics using a single (a part of) frame error trace. We use \( f_C(1) \) to denote probability of frame error as seen by time-averages. Correspondingly, \( (1 – f_C(1)) \) denotes probability of correct frame reception.

To model a covariance stationary frame error trace we use discrete-time doubly-stochastic model modulated by irreducible aperiodic Markov chain with finite number of states. According to this model, each state is associated with different bit error probabilities. We use only two states of the modulating Markov chain. ACF of such a process is geometrically distributed and may produce good approximation of empirical ACF \([14]\). This process is known as switched Bernoulli process (SBP). In \([14]\) it was shown that the only process with two-states of the Markov chain capturing frame error probability and lag-1 autocorrelation of the (covariance stationary) frame error process is given by

\[
\begin{aligned}
\alpha &= (1 – \lambda)E[W_C] \\
\beta &= (1 – \lambda)(1 – E[W_C])
\end{aligned}
\]

\[
\begin{aligned}
f_1(1) &= 0 \\
f_2(1) &= 1.
\end{aligned}
\]

where \( f_1(1) \) and \( f_2(1) \) are probabilities of error in states 1 and 2, respectively, \( \lambda \) is the non-unit eigenvalue of the transition probability matrix of the modulating Markov chain, \( E[B] \) is the mean of the bit error process, \( \alpha \) and \( \beta \) are probabilities of transition from state 1 to state 2 and from state 2 to state 1, respectively. According to the algorithm \( \lambda = K_C(1) \), where \( K_C(1) \) is the lag-1 autocorrelation \([14]\).

6 Performance evaluation

The arrival process from the traffic source is represented by D-BMAP. The frame error process is modeled by SBP, which is a special case of D-BMAP. According to the proposed performance evaluation model, the frame service process is then represented by D-BMAP_A+SBP_C/D/1/K system with non-preemptive priority discipline, where subscripts \( A \) and \( C \) are used to distinguish between frame arrival and error processes.

6.1 Description of the system

Since both arrival processes are independent of each other one can define their superposition that is D-BMAP. It allows to consider D-BMAP/D/1/K queuing system, where the arrival process, denoted by \{W(n), n = 0, 1, \ldots \}, is the superposition of \{W_C(n), n = 0, 1, \ldots \} and \{W_A(n), n = 0, 1, \ldots \}. Analysis of D-BMAP/D/1/K queuing system was carried out in many studies. Here, we take the method of imbedded Markov chain.

Time diagram of D-BMAP/D/1/K queuing system is shown in Fig. 2. According to such a system frames arrive in batches, batch of frames arrives just before the end of a slot. Frames are not allowed to enter service immediately and the service of any frame starts at the beginning of a slot. The state of the system is observed just after the slot boundary and these points are imbedded Markov points. The sojourn (service) time is counted as
the number of slots spent by a frame in the system. The system can accommodate at most $K$ frames. We assume partial batch acceptance strategy. According to this strategy, if a batch of $R$ frames arrives when $k$ frames are in the system and $R > (K - k)$, only $(K - k)$ frames are accommodated and $(R - K + k)$ frames are discarded. We consider a share of the wireless channel as a server with service time equal to a unit, i.e. time to transmit a single frame at the wireless channel.

![](image)

**Fig. 2.** Time diagram of the late arrival discrete-time queuing system.

### 6.2 Steady-state distribution of D-BMAP/D/1/K

Consider the system at the end of an arbitrary slot. The following equation relating the number of frames in the system between successive imbedded Markov points is the integral part of the imbedded Markov chain approach

$$S_Q(n + 1) = \max(0, S_Q(n) - 1) + \min(W(n + 1), K - S_Q(n)).$$

Observing (3), it follows that the arrival from the frame error process is not accepted by the system in the slot $(n + 1)$ if and only if the number of customers in the system in the slot $(n - 1)$ is zero, there is an arrival of $K$ frames in the time slot $n$, and one frame arrives from the frame error process in the slot $(n + 1)$. Contrarily, if there is at least one frame in the system in the slot $(n - 1)$, one frame departs at the end of $(n - 1)$ slot, and the number of frames in the system in the slot $n$ is less than $K$. Thus, the frame from the frame error process (if any) is not lost in the slot $(n + 1)$. To assure that the frame from the frame error process is always accepted by the system we do not allow the number of arrivals from both processes to be more than $K - 1$. This implies that the maximum number of arrivals from the frame arrival process is $K - 2$.

Complete description of the queuing system requires two-dimensional Markov chain $\{S(n), S_Q(n), n = 0, 1, \ldots\}$ imbedded at the moments of frame departures from the system, where $S(n) = S_A(n) \otimes S_C(n)$ is the state of superposition of the frame error and frame arrival processes, and $S_Q(n) \in \{0, 1, \ldots, K\}$ is the number of frames in the system just after frame departures. Introducing matrices $D(\geq k), k = 0, 1, \ldots, K$, containing transition probabilities with at least $k = 0, 1, \ldots, K$ arrivals, respectively, one can define the transition probability matrix, $T$, of the Markov chain $\{S(n), S_Q(n), n = 0, 1, \ldots\}$ [15]. Let $\mathbf{x} = (x_{0,1}, \ldots, x_{K,M})$ be the row array containing steady-state probabilities of $\{S(n), S_Q(n), n = 0, 1, \ldots\}$. Solving matrix equations $\pi T = \pi$, $\mathbf{1} e = 1$, one can compute steady-state probabilities $x_{kj} = \lim_{n \to \infty} Pr\{S_Q(n) = k, S(n) = j\}$. There are a number of algorithms to compute these probabilities.
6.3 Superposition of arrival processes

To proceed we have to determine superposition of the SBP model of the frame error process, \( \{W_C(n), n = 0, 1, \ldots\} \), and the D-BMAP model of the frame arrival process, \( \{W_A(n), n = 0, 1, \ldots\} \). Let \( \{W(n), n = 0, 1, \ldots\} \) to denote this superposed process. The transition probability matrix of the underlying Markov chain is given by \( D = D_A \otimes D_C \). To completely parameterize \( \{W(n), n = 0, 1, \ldots\} \) we have to determine transition probability matrices \( D(k), k = 0, 1, \ldots, K - 1 \). These matrices are defined as follows

\[
D(0) = D_A(0) \otimes D_C(0), \quad D(k) = \sum_{i=k-1}^{k} D_A(i) \otimes D_C(k - i).
\]

We also need transition probabilities matrices \( D(k), k = 0, 1, \ldots, K - 1 \) in the following form \( D(m, 0) = D_A(m) \otimes D_C(0), m = 0, 1, \ldots, K - 2 \), and \( D(m - 1, 1) = D_A(m - 1) \otimes D_C(1), m = 0, 1, \ldots, K - 2 \) for which the following holds \( D(m) = D(m, 0) \otimes D(m - 1, 1) \).

6.4 Loss performance

Probability function of lost frames. Since we guaranteed that the frame error process does not suffer losses, from the loss performance point of view D-BMAP\(_A\)+D-MAP\(_C\)/D/1/K and D-BMAP/D/1/K queuing systems are equivalent. Consider the loss behavior of D-BMAP/D/1/K queuing system between two arbitrary imbedded Markov points at equilibrium. Let the RV \( L, L \in \{0, 1, \ldots, K - 2\} \), denote the number of lost frames in a slot and let \( f_L(l) = Pr\{L = l\}, l = 0, 1, \ldots, K - 2 \), be its PF. Since at most \( (K - 2) \) frames may arrive from the frame arrival process, there can be at most \( (K - 2) \) lost frames in a slot. According to our assumptions the frame arrival process does not suffer losses when there are no frames in the system. Consider the event when \( l, l = 1, 2, \ldots, K - 2, \) frames are lost in this time slot. This event occurs when the following conditions are met

- there are \( k, k = 1, 2, \ldots \) frames in the buffer in the slot \( n - 1 \);
- there are at least \( (K - k + l) \) arrivals to the system in the slot \( n \).

To determine \( f_L(l) = Pr\{L = l\}, l = 1, 2, \ldots, K - 2 \), we have to take into account these conditions over all possible transitions of the underlying Markov chain with exactly \( (K - k + l) \) arrivals. We get the following

\[
f_L(l) = \sum_{k=2}^{K-1} \mathbf{x}_k D(K - k + l) \mathbf{e}, \quad f_L(0) = 1 - \sum_{l=1}^{K-1} f_L(l), \quad l = 1, 2, \ldots, K - 2,
\]

where \( \mathbf{e} \) is the vector of ones of appropriate size and recall that \( D(k) = 0, k > K - 1 \).

Moments of loss distributions. Mean and variance of the number of lost frames can be directly obtained from (5) as follows

\[
E[L] = \sum_{l=1}^{K-2} l f_L(l), \quad \sigma^2[L] = E[L^2] - (E[L])^2.
\]

\(^2\text{Recall that the maximum number of arrivals from was set to } (K - 1).\)
Probability of at least one frame loss. Let \( f_L(l > 0) \) be the probability of at least one frame loss. Considering these conditions over all possible transitions of the underlying Markov chain of \( \{W(n), n = 0, 1, \ldots\} \) with more than \((K - k + l)\) arrivals we get

\[
f_L(l > 0) = \sum_{k=2}^{K-1} x_k D(\geq K - k + 1)e. \tag{7}
\]

6.5 Delay performance

Probability function of delay. Consider a system at equilibrium and observe an arbitrary slot \( n \). Let us tag an arbitrary frame of the arrival process that arrives in this slot. Let the RV \( Q, Q \in \{1, 2, \ldots\} \), denote the delay (sojourn time) of an arbitrary frame and let \( f_{Q}(q) = Pr\{Q = q\}, q = 1, 2, \ldots, \) be its PF. The delay suffered by an arbitrary frame is the sum of the service time and time it spends in the buffer. Since higher priority arrivals may interrupt the ongoing service of arrivals of interest, the maximum delay, that a given frame may experience in the system is virtually unlimited.

Let \( f_{Q,j}(q|\sum_{l=0}^{q-1}W_C(n+l) = 0) \), \( q = 1, 2, \ldots, K \), be conditional PF of delay of the tagged arrival given that there are no arrivals from the frame error process in slots \( n, n+1, \ldots, (n+q-1) \) and the modulating Markov chain changes its state from \( i \) to \( j \), \( f_{Q,j}(q|\sum_{l=0}^{q-1}W_C(n+l) = 0) = Pr\{Q = q|W_C(n) = 0, \ldots, W_C(n+q-1) = 0, S(n) = i, S(n+q-1) = j\} \). These probabilities are then combined in matrices \( f_Q(q|\sum_{l=0}^{q-1}W_C(n+l) = 0) \), \( q = 1, 2, \ldots, K \). It is easy to observe that conditioning on \( W_C(n) = 0, W_C(n+1) = 0, \ldots, W_C(n+q-1) = 0 \) ensures that the frame does not suffer delay that is greater than \( K \) slots. Indeed, at most \((K-1)\) arrivals can be observed in the system and their service is not interrupted due to \( \sum_{l=0}^{q-1}W_C(n+l) = 0 \). Distinguishing between \( S_Q(n) = 0 \) and \( S_Q(n) \neq 0 \) we have the following expressions for \( f_Q(q|\sum_{l=0}^{q-1}W_C(n+l) = 0) \), \( q = 1, 2, \ldots, K \)

\[
\begin{align*}
f_Q&\left(q|\sum_{l=0}^{q-1}W_C(n+l) = 0\right) = \sum_{m=w}^{K-1} x_0 D(m, 0) \phi_m, \quad k = 0, \\
&\sum_{m=w}^{K-1} x_k D(m, 0) \phi_m, \quad k \neq 0, \tag{8}
\end{align*}
\]

where \( \phi_m \) is the probability that the tagged frame is at the \( i^{th} \) place in the arrival batch. Since an arrival from the frame error process does not occur \((W_C(n) = 0)\), all frames in the arrival batch have the same priority. Thus, \( \phi_m \) is independent of the actual position of the tagged arrival in the batch, has uniform distribution over \( m \) and given by \( \phi_m = 1/m \).

Note that in (8) only arrivals from the frame arrival process in the slot \( n \) are taken into account. However, place of the tagged arrival also depends on whether there is an arrival from the frame error process. Consider the event when the tagged arrival suffers \( q \), \( q = 1, 2, \ldots \) slots delay. This event occurs when the following conditions are simultaneously met as shown in Fig. 3:

- tagged arrival at the \( i^{th} \) position, \( i \leq q \), in the arrival batch in slot \( n \);
- \((q - i)\) arrivals from \( \{W_C(n), n = 0, 1, \ldots\} \) in successive \((q - 1)\) slots;
- no arrival from \( \{W_C(n), n = 0, 1, \ldots\} \) in the slot \((n + q)\).
The first condition has been found in (8), the latter one is given by
\[ D(\cdot, 0) = \sum_{i=0}^{K-2} D(i, 0). \] (9)

Using \( D(\cdot, 0) = \sum_{i=0}^{K-2} D(i, 0) \) and \( D(\cdot, 1) = \sum_{i=0}^{K-2} D(i, 1) \) we introduce transition probability matrices \( T(i, m), i = 0, 1, \ldots, m, m \geq i \), with exactly \( i \) arrivals from \( \{W_C(n), n=0,1,\ldots\} \) in \( m \) successive slots, starting from the slot \( n \). These matrices are given by
\[
T(0, m) = D^m(\cdot, 0),
\]
\[
T(1, m) = \sum_{k=m-1}^{0} D^{m-k-1}(\cdot, 0) D(\cdot, 1) D^k(\cdot, 0),
\]
\[
T(2, m) = \sum_{k=0}^{m-2} \left( D^k(\cdot, 0) D(\cdot, 1) \sum_{i=m-k-2}^{0} D^{m-i-k-2}(\cdot, 0) D(\cdot, 1) D^i(\cdot, 0) \right),
\]
\[
\ldots
\]
\[
T(m-1, m) = \sum_{k=m-1}^{0} D^{m-k-1}(\cdot, 1) D(\cdot, 0) D^k(\cdot, 1),
\]
\[
T(m, m) = D^m(\cdot, 1),
\] (10)
where \( T(i, m), i = 3, 4, \ldots, m \) can be obtained by induction from \( T(2, m) \) or \( T(m-2, m) \). The easiest way is to deduct \( T(i, m), i = 3, 4, \ldots, \lfloor m/2 \rfloor \), from \( T(2, m) \) and \( T(i, m), i = m, m-1, \ldots, \lceil m/2 \rceil \), from \( T(m-2, m) \). Combining (8), (9), and (10) we get an expression for PF of delay suffered by an arriving frame.

7 Conclusion

We identified a class of priority queuing systems capable to model the frame transmission process over wireless channels. We showed that the discrete-time priority queuing systems of \( \sum_i^{D-BMAP_A}/D/1/K \) type are well suited for this purpose. We studied \( D-BMAP_A+SBP_C/D/1/K \) non-preemptive system, where \( D-BMAP_A \) is used to model frame arrival process from the traffic source and \( SBP_C \) represents the frame error process. The
proposed model provides accuracy of the approach, introduced in [4], and versatility of that, presented in [5]. The latter is due to queuing-theoretic origin of the model. Accuracy is due to unbiased representation of wireless channel characteristics. According to our performance model both frame arrival and frame error processes are allowed to have distributional and autocorrelation properties of Markovian type.

References