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Full Length Research Paper

Performance analysis of ultra wideband media access control protocol providing two class traffic

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Ultra wideband (UWB) technology based primarily on the impulse radio paradigm has a huge potential for revolutionizing the world of digital communications especially wireless communications. Multiple packets can be assembled into a single frame at the medium access control (MAC) layer, which can significantly improve the throughput performance. This paper presents a detailed performance analysis for UWB multi-band MAC protocol. The MAC protocol is presented as two different clases. The first class involves all bands as data bands, while in the second calss one of its band is used for traffic control. The analysis is based on using multi-server queuing model and a detailed simulation. Each data band is represented as a server in the queuing model. The analysis is complemented with extensive simulations. In the experimental results, the protcol performance is presented as mean packet size, average packet delay, and blocking probability. A number of important conclusions were outlined from this study. First, the increase of transition rate between two classes has noticeable effect on the average number of packets in the queue and in the system, while the increase of the utilization rate U has a remarkable same effect. Next, the absence of one data band effects on the average number of packets decreases as the transmission rate decreases. Finally, the use of a multi-band approach provides an inherent flexibility in operation to coexist with other wireless networks.

Key words: Ultra wideband (UWB), wireless communications, medium access control (MAC), ad hoc networks, multi-server queuing model.

INTRODUCTION

Ultra wideband (UWB) is the cutting edge wireless short-range technology which has been the focus of interest in both academia and industry for applications in wireless communications (Karapistoli, 2012; Federal Communications Commission, 2002; Cuomo et al., 2002; Ghavami et al., 2004). UWB technology has many benefits owing to its UWB nature, which include high data rate, less path loss and better immunity to multipath propagation, availability of low-cost transceivers, low transmit power and low interference (Agusut and Ha, 2004; Merz et al., 2005). Further, the UWB spectrum can be partitioned into multiple comparatively narrow frequency bands that are mutually orthogonal and can be used simultaneously. This will lead to the use the available spectrum more efficiently (Chaudhry et al., 1992; Di Benedetto et al., 2005).

There are two types of UWB wireless communication approaches, the single-band approach and the multi-band approach. In the single-band approach, the communication is based on using a single band with time-hopping as the basic means of access (Federal Communications Commission, 2002). However, in the multi-band approach the available frequency bandwidth is divided into *B* bands. *B - 1* of these bands are used for data transmissions and are referred to as data bands. The remaining band is used for request control packets only (Broustis et al., 2006, 2007).

There has been mutliple research works on the design of the medium access control (MAC) protocol for multi-band UWB-based wireless networks that support ad hoc communications. For example, (Broustis et al., 2006, 2007), a multi-band MAC protocol for use with UWB-based ad hoc networks has been proposed. The proposed protocol design is based on separation of

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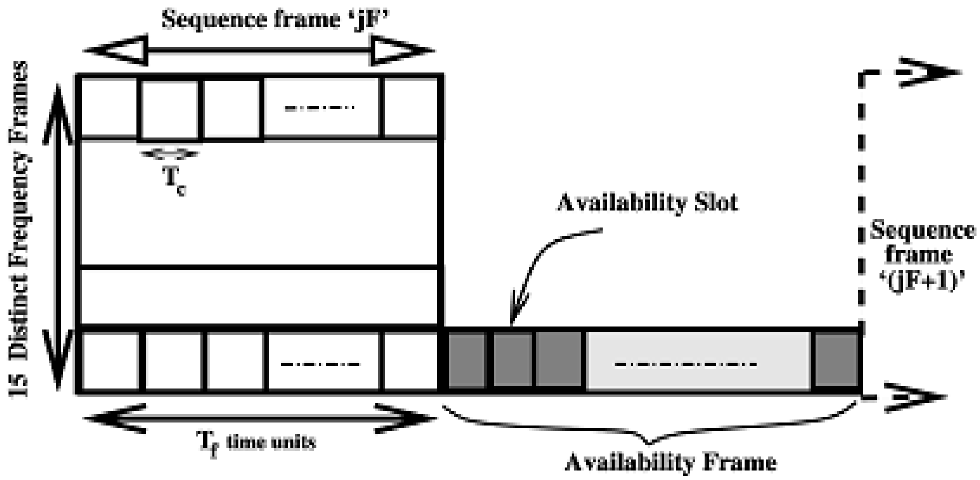

Figure 1. The frame structure multi-band MAC protocol.

control and data onto different bands. Simply, each data exchange begins with a rendezvous transaction on a control channel, where one node sends an explicit request message to the other, which signals its preparation to continue through a simple partial-response message. Subsequently, the two nodes switch their attention to the data bands and select one of them for the actual data exchange using first come, first serve (FCFS) discpline. This separation has two main advantages. First, since all nodes share a common unreserved channel only for short control messages, the contention on the shared channel is limited. Second, once a pair of nodes agrees to communicate on a data band, the communication can be continuous (no need for the use of time hopping sequences), and thus, it is highly efficient. The presented result indicate that the throughput of the proposed scheme is significantly higher compared to a single-band approach that combats delay spread by increasing the spacing between pulse transmissions.

This study aims to provide a detailed performance analysis for UWB multi-band MAC protocol. This is performed by analyzing the performance UWB multi-band MAC protocol in terms of utilizing the multiple bands. The analysis is based on using multi-server queuing model. This queuing model has been firstly explored by Chaudhry et al. (1992), Jurdak et al. (2005), Shoukry et al. (1994), and Shoukry et al. (1995). In the presented model, the data bands B are used instead of servers C in the multi-server queuing model (M[x]/M/B; B-1/FCFS), which in turn are responsible for the data transmission between users in a wireless ad hoc network. Finally, the effectivness of the presented model is evaluated using extensive simulations.

THE MULTI-BAND MAC PROTOCOL OVERVIEW

Here, a brief overview is given on the basic concepts and the operation of the multi-band MAC protocol. The key idea is to have a communicating pair of nodes exchange data over a private band as opposed to a single common band. In the multiple bands, the available frequency bandwidth is divided into *B* bands. *B−1* of these bands are used for data transmissions, called data bands. The remaining band is used for request control packets only, called the Request Band or Req-Band, and is usually assigned to the first band. The multi-band MAC protocol is designed based on the physical separation of the available UWB bandwidth of 7.5 GHz into multiple bands, each of which spans 500 MHz of the spectrum (Broustis et al., 2007).

Frame structure

Figure 1 shows the frame structure of the multi-band MAC protocol. Across all the bands, time is broken into superframes, which are separated by smaller availability frames. All data and control communication takes place during superframes. The availability frame is used to indicate whether each band will be busy or not in the next superframe. The availability frames alleviate the possibility of collisions of data transmissions in the superframes. Further, each superframe consists of *F* sequence frames, each of which in turn consists of T_f/T_c chip-times. The availability frame is sandwiched between the last sequence frame of the j^{th} superframe and the first sequence frame of the $(j+1)^{st}$ superframe (Broustis et al., 2007).

Operations of the MAC protocol

The protocol implementation at each node can be represented by a finite state machine, as shown in Figure 2. The available bandwidth is divided into B bands as follows:

1) One band for request and information about the state of both sender and reciever (control band).
2) The rest bands for data transmissions and acknowledgements (data bands).

The band availability maps into the following frames:

3) Superframes: Transmission of all control and data packets.
4) Availability frames: Declare intention to keep using a band.

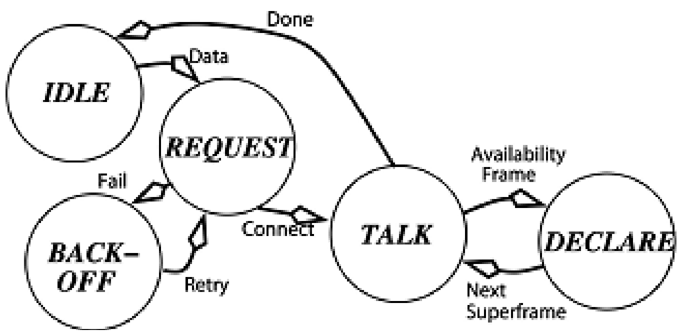

Figure 2. Depiction of the multi-band MAC protocol operations.

MULTI-SERVER QUEUING MODELING

Here, we study a multi-server queuing model (*M[x]/M/C; C-1/FCFS*) to discuss multi-band MAC protocol so we specify data bands *B* instead of servers *C*. As a result, the multi-server queuing model will be in the form (*M[x]/M/B; B-1/FCFS*), which in turn is responsible for transmission of data between users in wireless ad hoc networks using UWB technique.

Model description

In the multi-server queuing model, packets arrive in batches according to compound Poisson process with mean batch arrival rate λ (Chaudhry and Grassmann, 1979). Let *N(t)* be the number of batches of packets which have arrived by time t where {*N (t), t* ≥ 0} can be modeled as a Poisson process. Next, we fit a discrete distribution to the sizes of the successive batches where the batch sizes must be positive integers. Thus, the total number of packets to arrive by time *t* denoted by *Z*(*t*) is given by:

$$Z(t) = \sum_{i=1}^{N(t)} x_i \quad for \quad t \geq 0 \tag{1}$$

Where x_i is the number of packets in the *i*th batch. The x_i's are assumed to be independent identically distributed random variables which are also independent of {*N(t), t* ≥ 0}, then the stochastic process {*Z(t), t* ≥ 0} is said to be a compound Poisson process. In this case, the arrival batch size *X* has a positive Poisson distribution where no batch size equals zero, so we will exclude the value zero from the Poisson distribution that is given as:

$$P(x;\theta) = \theta^{x} e^{-\theta}/x!,\ x \geq 0,\ \theta > 0 \tag{2}$$

Now, let {a_x} represent a probability sequence that governs batch size (that is, an arriving batch has size *x* with probability a_x). This probability a_x is defined as:

$$a_x = P(x;\theta)/[1-P(0;\theta)] = \frac{\theta^{x} e^{-\theta}/x!}{1-e^{-\theta}} \tag{3}$$

Where θ is a parameter of batch size. The average batch size m in this case will be given by:

$$E(X) = \theta/(1-e^{-\theta}) = m \tag{4}$$

Packets are served according to exponential service time distribution with parameter $\mu > 0$. The B and (B-1) in the model notation above are the number of parallel data bands. Service is on a FCFS basis. In addition, the queue length in our model is assumed to have no limit. As indicated by the notation ($M^{[x]}/M/B;B-1/FCFS$), batches of packets arrive at random times with mean packet arrival rate λ. We investigate specifically a distribution of the batch size, namely a positive Poisson batch sizes. The queuing system under study has homogeneous parallel data bands where service time has exponential distribution with mean 1/μ. Our system alternates between two types of classes of system operation, this is due to the type of information that senders desire to communicate. In one class-1 of operation all *B* data bands are available and in the other class-0 only (*B-1*) data bands are available. The possibility of collisions due to multiple new senders choose the same band. This means that only one data band is allowed to collide randomly according to a discrete uniform distribution that assigns one of the data bands to be out of service where the band collision has equal chance over all data bands in the system. The mean time that the system operates with *B* data bands and (*B-1*) data bands is 1/α and 1/β, respectively.

The queue discipline for batches of packets is FCFS, while the service discipline within the batches is based on randomly choosing one of the packets mentioned earlier. If a batch of *r* packets arrives, while the system has *n* requested senders and *B-r* ≥ *1* and *r* ≥ *B-n*, then *B-n* are served immediately. The *r-B+n* delayed senders must wait for *d* departures, *d* = 1,2,.… , *r-B+n*. On the other hand, if the packet arrives while the system is in state *n*, *n* ≥ *B*, all the *r* packets are delayed. Thus, of these *r* packets who arrive when *n* = *B+k*, *k* = 0, 1, 2…, the packets under consideration must wait for d departures, *d* = *k+1*, *k+2*, …, *k+r*. The conditional probability of the packets waiting for *d* departures before its service commences, given the state of the system *n* just before the arrival of the packet's batch, is given by,

$$\sum_{r=B-n+d}^{\infty} \frac{r a_r}{m}\frac{1}{r} = \frac{1}{m}\sum_{r=B-n+d}^{\infty} a_r,\quad d = 1, 2, \ldots 0 \leq n \leq d + B - 1 \tag{5}$$

Where the batch size *X* is a random variable with distribution given by:

$$a_r = P(X = r),\ r \geq 1$$

and *X* has mean *m* , $0 \leq m = \sum_{r=1}^{\infty} r a_r < \infty$, and variance σ^2, 0 < $\sigma^2 < \infty$

Packets of certain batch are served randomly. If *X* is the size of a batch, then packet *i*, *i =1,2,…,X* has the same chance of joining service. In order to generate an equal chance to all packets in a given batch of size *X*, either a uniform assignment of the order in which they may be served is used or using a predefined permutation sequence. This routine helps to organize every packet in the batch.

Modeling assumptions and notations

Table 1 shows the different notation which are used in the proposed model. The proposed model has many assumptions. First of all, the system at any instant of time is in one of two classes of operation Class-0 or Class-1. The requested packets are mobile and independent from each other to form an ad hoc network. Further, the queue has *B* identical exponential bands in parallel with each band having a service rateμ. Groups of packets arrive at a multi-band in accordance with Poisson process with parameter λ.

Table 1. Summary of parameters.

Parameter	Description
B	Number of data bands
N	The number of batches
λ	Mean batch arrival rate
μ	Constant service rate of a band
m	The average batch size
L_Q	The average number of data packets in the queue
W_Q	The waiting time per data packet in the queue
W_S	The waiting time per data packet in the system
L_S	The average number of data packets in the system
Class-1	All *B* data bands are available for serving the packets in this class
Class-0	All *(B-1)* data bands are available for serving the packets in this class
$P_{0,i}$	The probability of having no data packets to transmit in the system when the system is in Class-i, i = 0,1
β	Conversion rate from Class-0 to Class-1
α	Conversion rate from Class-1 to class-0
U	The utilization of traffic
θ	The parameter of the batch size distribution
T_C	Chip-time (time spacing between pulses)
P_B	The blocking probability that defines the probability that all data bands are busy.
Pe	Bit error probability (the expectation value of the BER (Bit Error Rate) which can be considered as an approximate estimate of the bit error probability)
CBR	Constant bit rate (the form of a technique which is used for the purpose of measuring the rate at which the encoding of the data packets takes place).

Packets are transmitted in accordance of batches to exchange data over the ad hoc network. The duration of the superframe (batch) is set to 11,200 *Tc*, *Tc* = 6 × 10 to 8 s. In the transmission process, we use both CBR = 0.04 s and Poisson traffic with arrival rate = 1/λ , the service time is exponential with the same mean 1/μ. The times that system operates with *B* data bands and (B-1) data bands has exponential distribution with mean 1/α and 1/β, respectively. The batch size *X* follows a positive Poisson distribution with parameter θ. Two or more packet transmissions sent at the same time on the same band will collide. All packets which collide will then initiate back-off timers, where they remain for a random delay before returning to the request state. The overall simulation time is 10000 s. Packets are served according to FCFS discipline, while nodes are served randomly. The utilization traffic for the system is given by $U = m\lambda / B\mu$ and the condition for existence of the steady state is $U < 1$.

The analysis approach

The simulation steps can be described in the following steps:

1) Generate 1000 random variables (indicated as *B* bands),
2) Generate 1000 interarrival times for 1000 different batches from exponential distribution with mean *1/λ*,
3) Generate a random batch size for each batch in step 2 using positive Poisson distribution with parameter *θ*,
4) To specify the service times for each packet in the successive batches, generate random variables from exponential distribution with mean 1/μ,
5) Specify the intervals of time that the system operates with *B* data bands by generating random variables from exponential distribution with mean 1/α,
6) To specify the intervals of time that the system operates with *(B-1)* data bands, generate random variables from exponential distribution with mean 1/β.
7) To specify which data band will be collide, generate random variables from discrete uniform distribution with parameter B. Where the integers 1, 2, 3,…,B occur with equal probability,
8) Calculate the event time of back-offs and retrying for each band based on the intervals of time during which the system works with *B-1* and *B* data bands, respectively,
9) Calculate the traffic rate *U* from equation $U = m\lambda/B\mu$,
10) Find the number of all packets that enter the system as a total of sizes of batches *N* that arrive to the system,
11) Convert the transfer rate from packets per second into bits per second where packet length = 8 bits/s,
12) Find the next arrival time of a batch and packet, respectively,
13) Specify the class at which an arriving batch will find the system as follows:

a) If the arrival time of a batch is greater than the event time of back-off and less than the event time of retrying, the system will be in Class-0.
b) If the arrival time of a batch is greater than event time of retrying and less than the event time of back-off, the system will be in Class-1.

14) An arriving packet will immediately start service if one of data bands is free or wait until any data band becomes free,
15) Calculate the departure time of a packet from system as the total of arrival time plus service time,

Table 2. Average number of packets in the queue L_Q.

U	Transition rate between two classes (Class-0 and Class-1)				
	0.000	**0.250**	**0.500**	**0.750**	**1.000**
0.100	0.067	0.069	0.078	0.084	0.093
0.200	0.165	0.337	0.547	0.859	0.928
0.300	1.014	1.676	2.309	2.840	3.415
0.400	4.095	4.822	5.163	6.175	6.954
0.500	7.471	7.954	8.457	9.047	9.885
0.600	10.598	11.201	11.891	12.576	13.356
0.700	14.021	16.896	18.835	22.012	25.869
0.800	28.170	32.549	44.705	62.976	87.874
0.900	92.825	130.172	200.513	310.145	408.679

Mean size of batch = 5.896; Number of data bands = 5.

16) Calculate the waiting time of a packet in the queue,
17) Calculate the waiting time of a packet in the system,
18) Calculate the busy time for each data band,
19) Calculate the departure time of a batch,
20) Calculate the total of waiting times of packets in queue,
21) Calculate the total of waiting times of packets in system,
22) Repeat Steps 17 to 21 until all packets in a given batch are served,
23) Define the different time intervals during which system operates in the two classes,
24) Repeat the steps from 13 to 26, 1000 times,
25) The probability that the system is in Class-i, i = 0,1, while there is no any packet in the system $P_{0,i}$ from equation,

$$P_{0,i} = \frac{\Sigma \text{ The number of batches that arrive to find the system is idle in Class-i, i = 0,1}}{\text{The number of all batches}}$$

26) Calculate the probability that no packets are in system P_0 from equation,

$$P_0 = \frac{\Sigma \text{ The number of batches that arrive to find the system is idle}}{\text{The number of all batches}}$$

Where, $P_0 = P_{0,0} + P_{0,1}$
27) Calculate the blocking probability P_B, that is, the probability that any packet in an arriving batch must wait from equation,

$$P_B = \frac{\text{The number of waiting packets in the queue}}{\text{The number of all packets}}$$

28) Calculate the average waiting time in queue W_Q from equation,

$$W_Q = \frac{\Sigma \text{ The waiting time per packet in the queue}}{\text{The number of all packets}}$$

29) Calculate the average waiting time in system W_S from equation,

$$W_S = \frac{\Sigma \text{ The waiting time per packet in the system}}{\text{The number of all packets}}$$

30) Calculate the average number of packets in the queue L_Q from equation,

$$L_Q = \frac{\Sigma \text{ The waiting time per packet in the queue}}{T_S}$$

31) Calculate the average number of packets in the system L_S from equation,

$$L_S = \frac{\Sigma \text{ The waiting time per packet in the system}}{T_S}$$

where T_S is the overall simulation time we observed in the system which equals 10000 s.

SIMULATION RESULTS

The simulation program was tested extensively for values of (*U*, *B*, *X*) where $0.1 \leq U \leq 0.9$, $1 \leq B \leq 100$ and batch size $X \leq 100$. Tables 2 to 7 contain two variables. The first variable represents the traffic utilization *S,* and the second variable represents transition rate between two classes which is equal $\alpha/(\alpha+\beta)$, while the other values inside each table represent performance measures (output data). These measures are Ls, L_Q, W_Q, W_S, P_0, P_B in Tables 2 to 7, respectively. Based on the approach explained previously, the input data contains the number of data bands *B*, the mean time that the system organizes with *B* data bands denotes by $1/\alpha$, the mean time that the system organizes with (*B-1*) data bands denotes by $1/\beta$, the number of batches *N*, the parameter size of batches θ, mean service time $1/\mu$ and the mean inter-arrival time $1/\lambda$. Different performance measures are calculated. These measures include:

i) The expected number of packets in the queue and in the system will be L_Q and L_S, respectively.
ii) The expected waiting time per packet in the queue and in the system are W_Q and W_S, respectively.
iii) The idle probability of having zero packets in the

Table 3. Average number of packets in the system L_S.

U	Transition rate between two classes (Class-0 and Class-1)				
	0.000	**0.250**	**0.500**	**0.750**	**1.000**
0.100	0.185	0.437	0.647	0.959	1.328
0.200	1.854	2.586	3.079	3.840	4.415
0.300	4.914	5.776	6.109	6.940	7.315
0.400	7.995	8.722	9.563	9.975	10.554
0.500	10.971	11.654	12.057	12.977	13.885
0.600	14.598	17.241	20.801	23.546	28.156
0.700	30.021	35.996	40.635	46.012	52.869
0.800	58.270	67.569	74.305	84.076	92.814
0.900	110.025	162.176	220.463	340.185	418.669

Table 4. Average waiting time of packets in the queue W_Q.

U	Transition rate between two classes (Class-0 and Class-1)				
	0.000	**0.250**	**0.500**	**0.750**	**1.000**
0.100	0.185	0.237	0.367	0.480	0.598
0.200	1.274	1.986	2.779	3.340	3.995
0.300	4.714	5.276	6.309	7.240	8.315
0.400	8.959	9.772	10.534	11.375	12.254
0.500	12.071	15.624	18.657	22.977	25.885
0.600	24.598	32.211	40.401	48.546	53.156
0.700	43.021	58.596	78.335	98.012	118.869
0.800	88.250	120.579	144.335	179.076	214.514
0.900	157.025	223.162	350.463	470.185	578.669

Mean size of batch = 5.896; Number of data bands = 5.

Table 5. Average waiting time of packets in the system W_S.

U	Transition rate between two classes (Class-0 and Class-1)				
	0.000	**0.250**	**0.500**	**0.750**	**1.000**
0.100	1.185	1.337	1.767	2.280	2.998
0.200	3.284	3.956	4.779	5.340	5.995
0.300	6.724	7.276	8.309	9.040	9.908
0.400	11.959	13.772	15.594	17.395	19.254
0.500	22.571	25.694	30.617	35.907	40.625
0.600	40.998	44.251	48.401	55.576	63.196
0.700	63.441	80.526	95.335	108.012	138.869
0.800	122.210	142.529	164.352	189.456	224.564
0.900	197.725	255.162	360.463	490.185	598.669

Mean size of batch = 5.896; Number of data bands = 5.

system P_0.
iv) The probability that all bands are busy, blocking probability P_B.

We note that the traffic utilization U changes with variation in the value of 1/μ. So the value of transition rate between two classes (Class-0 and Class -1) is varied due to the changes in values 1/α and 1/β. Results shown in Tables 2 to 7 are obtained by these input data. Figures 3 to 8 are the explanations for Tables 2 to 7, respectively. These graphs show the effect of performance measures on the system resulting for different traffic utilization U and transition rate between two classes. For example, Figure 3 denotes the relation among traffic utilization

Table 6. The idle probability of having zero packets in the system P_0.

U	Transition rate between two classes (Class-0 and Class-1)				
	0.000	**0.250**	**0.500**	**0.750**	**1.000**
0.100	0.838	0.844	0.851	0.825	0.816
0.200	0.775	0.787	0.797	0.762	0.755
0.300	0.651	0.662	0.685	0.632	0.619
0.400	0.537	0.566	0.596	0.515	0.459
0.500	0.368	0.392	0.432	0.349	0.299
0.600	0.249	0.264	0.293	0.228	0.187
0.700	0.165	0.188	0.205	0.135	0.106
0.800	0.076	0.109	0.148	0.049	0.034
0.900	0.0246	0.0514	0.0877	0.0211	0.0032

Mean size of batch = 5.896; Number of data bands = 5.

Table 7. The probability that all bands are busy, blocking probability P_B.

U	Transition rate between two classes (Class-0 and Class-1)				
	0.000	**0.250**	**0.500**	**0.750**	**1.000**
0.795	0.772	0.755	0.737	0.717	0.100
0.855	0.812	0.795	0.778	0.757	0.200
0.889	0.862	0.831	0.792	0.785	0.300
0.918	0.895	0.876	0.846	0.826	0.400
0.944	0.919	0.898	0.872	0.849	0.500
0.972	0.958	0.939	0.911	0.893	0.600
0.982	0.971	0.945	0.927	0.912	0.700
0.991	0.977	0.969	0.959	0.948	0.800
0.998	0.989	0.983	0.971	0.956	0.900

Mean size of batch = 5.896; Number of data bands = 5.

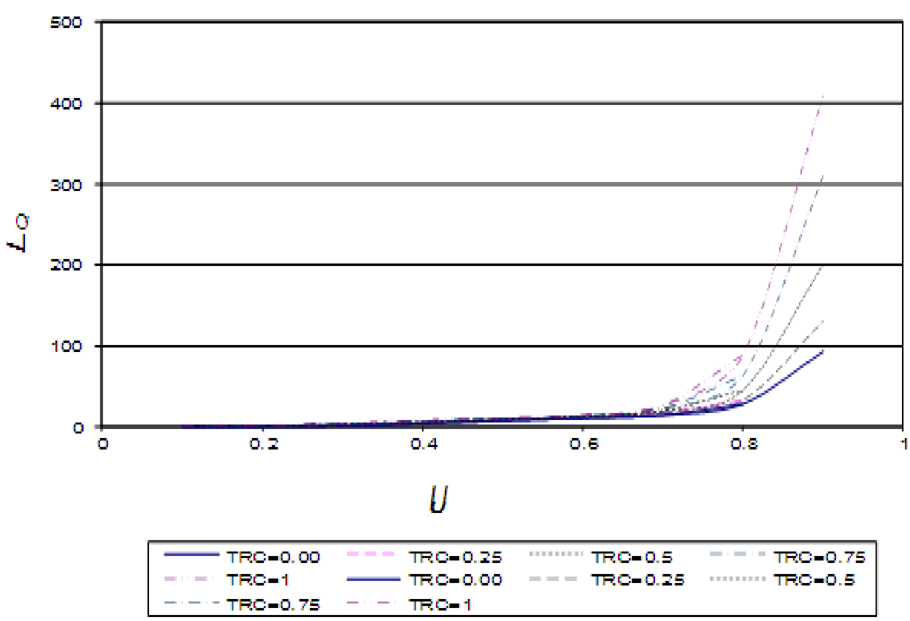

Figure 3. L_Q versus U where (m = 5.896, B = 5).

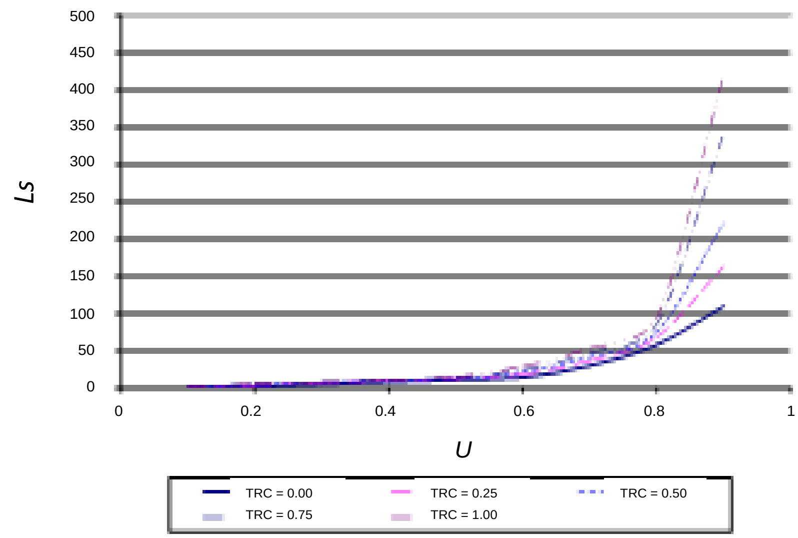

Figure 4. L_S versus U where (m = 5.896, B = 5).

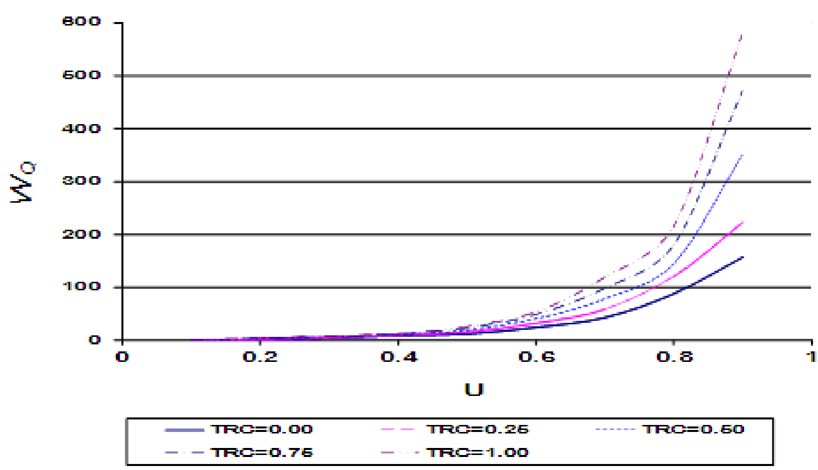

Figure 5. W_Q versus U where (m = 5.896, B = 5).

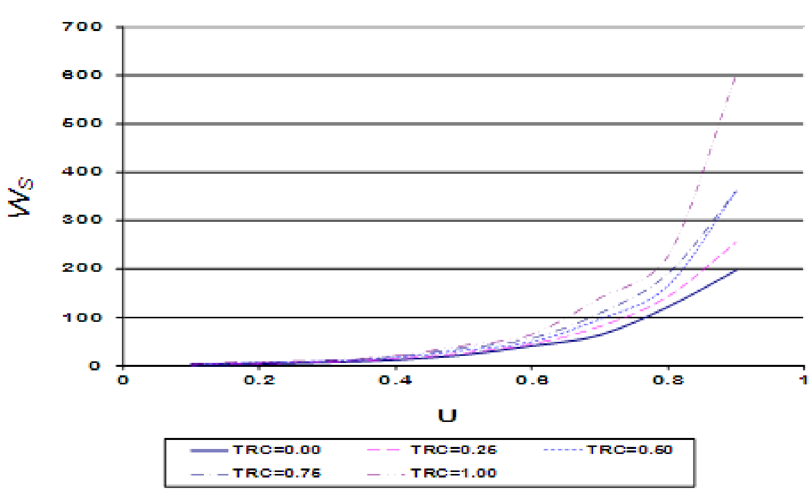

Figure 6. W_S versus U where (m = 5.896, B = 5).

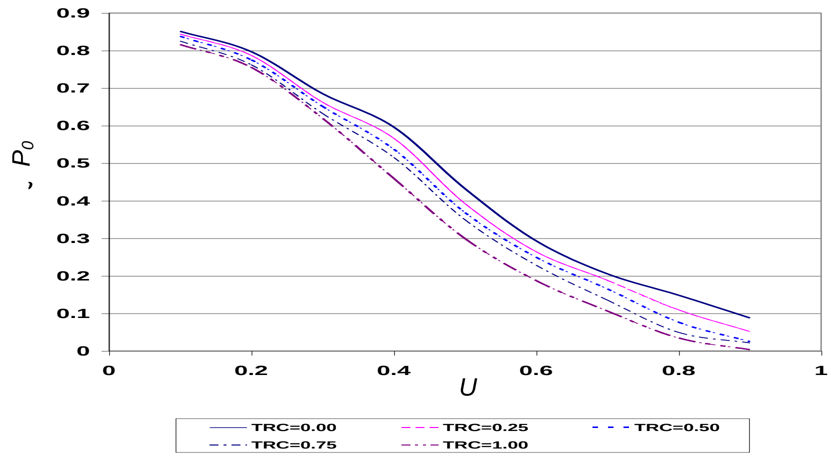

Figure 7. P_0 versus U where (m = 5.896, B = 5).

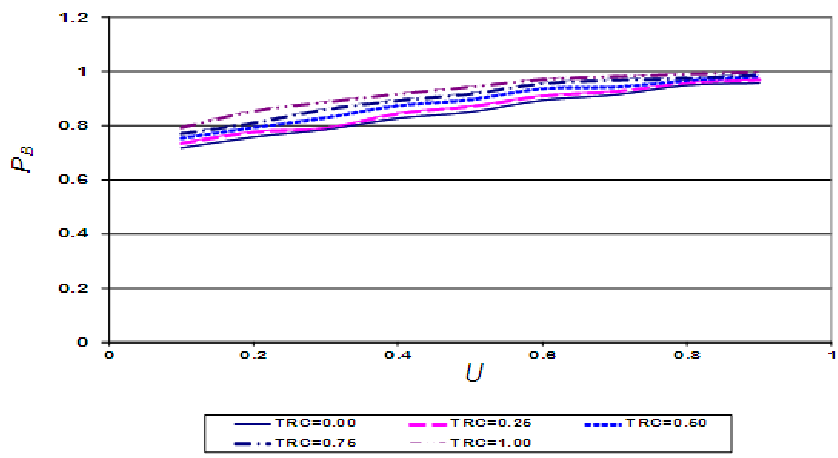

Figure 8. P_B versus *U* where (*m* = 5.896, *B* = 5).

U and the average number of packets in the queue L_Q with the increasing of transition rate between two classes TRC which equals α/(α+β).

Tables 2 and 3 show that the increases of transition rate between two classes (Class-0 and Class-1) has noticeable effect on the average number of packets in the queue and in the system, while the increase of the utilization rate *U* has a remarkable effect on the average number of packets in the queue and in the system. Further, the average number of packets in the queue and in the system increase as the average batch size increases. So, the increase of TRC affects both L_Q and L_S when the average batch size increases. The most effect on the average number of packets in the system and in the queue is happening when the utilization rate U is very close to unity. The absence of one data band affects the average number of packets as utilization rate is near the unity (heavy load traffic), which means that transmission rate decreases.

Tables 4 and 5 show that the averages waiting time in the queue as well as in the system is highly influenced by the absence of one of the bands for both low and high utilization rate of data bands. Table 6 shows the probability of having no packets in the system P_0 when a batch arrives. This means that the percentage of time the system is idle is not affected by the absence of one of the data bands; while P_0 decreases as TRC increases for the utilization rate, and P_0 decreases noticeably as TRC increases for the high utilization rate of bands. Moreover, P_0 decreases as the utilization rate of data bands increases.

Table 7 shows that the blocking probability P_B is highly influenced by the increase of the utilization rate of data bands, while P_B increases as the utilization rate increases. So, the blocking probability has remarkable effect resulting from absence of one of the data band, where it increases as the TRC increases.

Finally, the performance measures are changed in response to the changes of the operating parameters. We documented the behavior of the system when one of the data bands temporarily leaves the system with useful graphical representation to give an opportunity to notice the system behavior over the traffic utilization and the transition rate between two classes (Class-0 and Class-1). Further, the use of a multi-band approach provides an inherent flexibility in operation to coexist with other wireless networks. The approach we present is conjoint with the UWB physical layer and takes into account the regulations imposed by the FCC. One main requirement for real-time service is delay guarantee, as packets with a large delay may be considered useless and discarded.

Conclusion

In this study, we have presented a detailed performance analysis for UWB multi-band MAC protocol. The analysis is based on using multi-server queuing model and a detailed simulation. Each data band is represented as a server in the queuing model. A number of important conclusions were outlined from this study. First, the increase of transition rate between two classes (Class-0 and Class-1) has noticeable effect on the average number of packets in the queue and in the system, while the increase of the utilization rate U has a remarkable same effect. Next, the absence of one data band effects on the average number of packets decreases the transmission rate decreases. Finally, the use of a multi-band approach provides an inherent flexibility in operation to coexist with other wireless networks

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