KSII TRANSACTIONS ON INTERNET AND INFORMATION SYSTEMS VOL. 8, NO. 12, Dec. 2014

Throughput of Coded DS CDMA/Unslotted ALOHA Networks with Variable Length Data Traffic and Two User Classes in Rayleigh Fading FSMC Model

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Received January 17, 2014; revised April 10, 2014; revised September 9, 2014; accepted September 13, 2014; published December 31, 2014

Abstract

Previous papers analyzed the throughput performance of the CDMA ALOHA system in Rayleigh fading channel, but they assume that the channel coefficient of Rayleigh fading was the same in the whole packet, which is not realistic. We recently proposed the finite-state Markov channel (FSMC) model to the throughput analysis of DS uncoded CDMA/unslotted ALOHA networks for fixed length data traffic in the mobile environment. We now propose the FSMC model to the throughput analysis of coded DS CDMA/unslotted ALOHA networks with variable length data traffic and one or two user classes in the mobile environment. The proposed DS CDMA/unslotted ALOHA wireless networks for two user classes with access control can maintain maximum throughput for the high priority user class under high message arrival per packet duration.

Keywords: finite-state Markov channel (FSMC), code-division multiple access (CDMA), unslotted ALOHA, queueing analysis, Doppler frequency offset

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This work was supported in part by the Ministry of Science and Technology, Taiwan, under Grant NSC 98-2221-E-027-038-MY2

http://dx.doi.org/10.3837/tiis.2014.12.005

1. Introduction

Direct-sequence code-division multiple access (DS CDMA) is a wireless transmission technology which offers random access abilities and potential for higher throughput [1-7]. In [8-15], the DS CDMA/slotted ALOHA system is investigated in wireless and optical channels. In [16-20], the throughput of the DS CDMA/unslotted ALOHA system is analyzed in AWGN channels. The throughput analysis of the DS CDMA/unslotted ALOHA wireless network in Rayleigh fading channels has been conducted in [21-23]. They all assumed packet-level analysis, and ignore that the channel gain and/or multiple access interference level changes symbol-by-symbol within the packet. In [24], we proposed the finite-state Markov channel (FSMC) to analyze throughput performance of the uncoded DS CDMA unslotted ALOHA networks with fixed length data traffic. The channel gain as well as multiple access interference can vary from symbol by symbol.

In this paper, we propose the FSMC to analyze throughput performance of the coded DS CDMA unslotted ALOHA systems for variable message length with one or two user classes, and access control in mobile channels. This is an extension of our previous work in [24]. We add channel coding, variable length data traffic, and two user classes in this paper. We assign different priorities to two user classes by different packet transmission probabilities (access control), which improve the throughput of the higher priority user class in high offered load [18][19].

The significance of this extension is as follows:

- Proper channel coding in DS/CDMA unslotted ALOHA system can enhance the throughput because the error correction codes convert some unsuccessful packets transmission into the successful ones. This is confirmed in Figs. 4-6 in simulation results. In [24], however, channel coding is not used.
- The major data traffic types in today's mobile communications are electronic mail, multimedia file transfers, and web traffic which can all be modeled as variable message length traffic. In [24], however, one message equal to one fixed length packet (fixed length data traffic) is assumed. In this paper, we assume one message is equal to variable number of fixed length packets [17][20]. In other words, we assume variable message length and it is more suited to the major data traffic types in today's mobile communications.
- Many mobile users may require services with different qualities-of-service (QoS). We propose a DS/CDMA unslotted ALOHA system with two user classes and analyzed the throughput of the proposed system. The analysis complexity is significantly higher than that in [24]. The state transition diagram in Fig. 3 now become three-dimensional instead of two-dimensional in Fig. 2 of [24]. The packet success probability in (24) now has four-dimensional summation instead of two-dimensional one in (16) of [24]. In [24], however, there is only one user class, so different QoS is not possible.

The rest of this paper is organized as follows: In Section 2, the FSMC model is briefly introduced. In Section 3, the system model is presented. In Section 4, we analyze the throughput of the DS CDMA/unslotted ALOHA networks in Rayleigh fading FSMC channel for variable length data traffic and one/two user classes. The simulation and numerical results are given in Section 5. Section 6 is the conclusion.

2. FSMC Model (1-D Markov process)

In many cases, modeling a Rayleigh fading channel as a two-state Gilbert–Elliot channel [25][26] is not sufficient because the channel condition can vary dramatically. Extending the two-state model to a finite-state one is called FSMC model [27][28]. FSMC model depend on the condition that the users' received signal-to-noise ratio (SNR) may be highly time-varying in mobile channels.

Because a traditional time-varying Rayleigh fading channel, produce time-varying received SNR, by dividing the range of the received SNR into a finite number of interval, a FSMC model can be built for the Rayleigh fading channel. A finite state Markov chain channel is defined by its transition probabilities. We denote discrete-time Markov chain channel with state space $\{1,2,...,M\}$ and transition probability matrix $h=[h_{i,j}],\ \ 1\le i,j\le M$. The $h_{i,j}$ is defined as the probability that the Rayleigh fading channel changes from the state *i* to the state *j*. Let *A* denote the received SNR that is proportional to the square of the signal envelope. The probability density function (PDF) of *A* is exponential and can be written as

$$f_A(x)=\frac{1}{\xi}e^{-\frac{x}{\xi}} \tag{1}$$

Where ξ is the expected value of A .Let $0=A_0<A_1<\cdots<A_{M-1}<A_M=\infty$ be the thresholds of the received SNR. Therefore, the Rayleigh fading is said to be in the state j , j = 1, 2, …,M , if the received SNR is in the interval $[A_{j-1},A_j)$. N_j , $j\in\{1,2,\cdots,M\}$ is the expected number of the received SNR level crossing downward the boundary A_j at state *j* of FSMC, and can be written as

$$N_j=\sqrt{\frac{2\pi A_j}{\xi}}f_m e^{-\frac{A_j}{\xi}} \qquad j=1,2,\cdots,M \tag{2}$$

f_m is the maximum Doppler frequency and given by

$$f_m=\frac{v}{\lambda} \tag{3}$$

where *v* is the vehicle speed and λ is the wavelength.

We assume the interference levels depend on consecutive symbols are neighboring states. Then, the element of the transition probability matrix **H** is given by [27]

$$h_{i,j}=0,\quad \forall\,|i-j|>1 \tag{4}$$

We used a BPSK modulated communication system with a transmission rate of *R* bits per second. The average bit per second transmitted during which the radio channel is in state j is

$$R^{(j)}=R\varphi_j \tag{5}$$

where the steady state probability for each state is

$$\varphi_j=\int_{A_j}^{A_{j+1}}\frac{1}{\xi}e^{-\frac{x}{\xi}}dx=e^{-\frac{A_{j-1}}{\xi}}-e^{-\frac{A_j}{\xi}},\quad j=1,2,\cdots,M \tag{6}$$

Finally, we can get the approximated value of the transition probability as follows [27]

$$
\begin{aligned}
h_{j,j+1} &\approx \frac{N_{j+1}}{R^{(j)}}, \quad j \in \{1,2,\cdots,M-1\} \\
h_{j,j-1} &\approx \frac{N_j}{R^{(j)}}, \quad j \in \{2,\cdots,M\} \\
h_{j,j} &= 1 - h_{j,j-1} - h_{j,j+1}, \quad j \in \{2,\cdots,M-1\} \\
h_{1,1} &= 1 - h_{1,2} \\
h_{M,M} &= 1 - h_{M,M-1}
\end{aligned}
$$

3. System Model

We consider a single-carrier DS CDMA system with random spreading codes of length N in an unslotted ALOHA network for two user classes with variable message length. Each class's message has B_n $(n=1,2)$ fixed-length packets, where B_n is geometrically distributed with expected value $\overline{B_n}$.Where $\overline{B_1}$ and $\overline{B_2}$ are the average number of packets in a message for class 1 and class 2, respectively .The length of packet is fixed to be L bits, so the message length of class 1 and 2 are $B_1 L$ [bits] and $B_2 L$ [bits], respectively. We consider a single hub station and an infinite number of independent users in our system network. We use a Poisson process with an arrival rate λ_1 for class 1 and arrival rate λ_2 for class 2 to model the arrival process of the system for our system network.

The offered traffic load for the class n, of the network is defined as G_n (packets/packet duration), n=1, 2. The corresponding throughput is defined as S_n (packets/packet duration) , n=1, 2. Finally, the system throughput is defined as $S_{tot}=S_1+S_2$, respectively. It's easy to obtain the packet duration T_p [sec] by L multiplied by $1/R$, where R [bits/sec] is the data rate of system.

The bit-error probability of an asynchronous DS CDMA system [29] for k interfering users and FSMC channel state j by simplified improved Gaussian approximation is expressed as

$$
\begin{aligned}
P_b(k,j) = {} & \frac{2}{3} Q\left[\left(\frac{k}{3N} + \frac{1}{2A_j}\right)^{-0.5}\right] \\
& + \frac{1}{6} Q\left[\left(\frac{k(N/3)+\sqrt{3}\sigma}{N^2} + \frac{1}{2A_j}\right)^{-0.5}\right] \\
& + \frac{1}{6} Q\left[\left(\frac{k(N/3)-\sqrt{3}\sigma}{N^2} + \frac{1}{2A_j}\right)^{-0.5}\right]
\end{aligned} \tag{7}
$$

where

$$\sigma^2 = k[N^2 \frac{23}{360} + N(\frac{1}{20} + \frac{k-1}{36}) - \frac{1}{20} - \frac{k-1}{36}]$$

where $N_0/2$ is the two-sided power spectral density of Gaussian noise, E_b is the bit energy and $Q(x)$ is given by

$$Q(x)=\frac{1}{\sqrt{2\pi}}\int_x^{\infty}\exp(-\frac{u^2}{2})du \tag{8}$$

The third term of (7) may not be real-valued, if k is too small. If this occurs, we can use standard Gaussian approximation [30] instead,

$$P_b(k,j)=Q\left[\left(\frac{k}{3N}+\frac{1}{2A_j}\right)^{-0.5}\right] \tag{9}$$

In (7) and (9), bit errors in a packet are caused by the effect of the multiple access interference (MAI) and Rayleigh fading. The hub station decides the packet transmission probability $P_{tr,n}$ of class *n* users based on the offered load of class *n* users, G_n, n=1, 2, and then broadcasts the packet transmission probability to mobile stations (MSs). The total offered load must be less than $G_{\max}$, where $G_{\max}$ is the maximum offered load the system can reach. The packet transmission probabilities for low, medium, and heavy load are as follows [18][19]

$$\begin{cases} P_{tr,1}=1 & G_1\le G_{\max} \\ P_{tr,2}=1 & G_1+G_2\le G_{\max} \end{cases}$$
$$\begin{cases} P_{tr,1}=1 & G_1\le G_{\max} \\ P_{tr,2}=\dfrac{G_{\max}-G_1}{G_2} & G_1+G_2> G_{\max} \end{cases} \tag{10}$$
$$\begin{cases} P_{tr,1}=\dfrac{G_{\max}}{G_1} & G_1> G_{\max} \\ P_{tr,2}=0 & G_1+G_2> G_{\max} \end{cases}$$

4. Throughput Analysis For DS CDMA/UNLOTTED ALOHA System Combining FSMC Model

4.1 M/M/∞ Queueing Model

The DS CDMA/unslotted ALOHA system with variable message length and one/two user classes can be modeled as the M/M/∞ queuing model, as stated in our previous works in AWGN channels [19][20]. Here we briefly review the reasoning. We first recall a theorem from [31].

Theorem1[31]**:**For $M/G/\infty$ queueing model with arrival rate λ, the probability distribution for the number of packet in the system is given by

$$P_k = e^{-\lambda/\mu}\frac{(\lambda/\mu)^k}{k!} \quad k \geq 0 \tag{11}$$

where 1/μ is the average packet length.

The above theorem from [31] states that the number of users in M/G/∞ queuing system is function of the *average* packet length only, not the *distribution* of packet length. Thus M/M/∞ (exponential packet length) is equivalent to M/D/∞ (fixed packet length) for DS/CDMA unslotted ALOHA systems because the packet success probability depends on the number of users only (*the equivalence may not be true for other communication systems*). Thus, instead of the M/D/∞ queueing model with the death rate approximation in [17] (variable message length and one user class) [18] (variable message length and two user classes), we propose M/M/∞ queueing model for the DS CDMA unslotted ALOHA system [20] (variable message length and one user class) [19] (variable message length and two user classes). As shown in [17-20], when one message is equal to variable number of fixed length packets (variable message length), the analysis of variable message length in AWGN channels *follows (or bases on)* the analysis of fixed packet/message length (one message=one packet) in AWGN channels [16]. Therefore the DS CDMA/unslotted ALOHA system with variable message length and one/two user classes in FSMC fading channels can be modeled as the M/M/∞ queuing model like our previous works in AWGN channels [19-20].

4.2 Proposed Throughput Analysis for Variable Message Length and One User Class (2D Markov process)

In [24], they consider fixed message length and one user class in the FSMC model but they don't consider message is variable message length. Each message has independent and identically distributed exponential service duration with the departure rate as follows [20]

$$\mu = \frac{1}{T_p} \tag{12}$$

where μ depends on k because the departure rate in M /M /∞ queueing mode is proportional to the number of interfering users.

Because the one message is equal to variable number ($\overline{B}$ on average) of fixed length packets, the message arrival rate λ (messages/sec) is related to the average number of generated packets within a packet duration G (packets/packet duration) by the following simple conversion formula [17][20]

$$\lambda = \frac{G}{T_P \cdot \overline{B}} \tag{13}$$

The state transition diagram for M/M/∞queuing model is shown in **Fig. 1**.

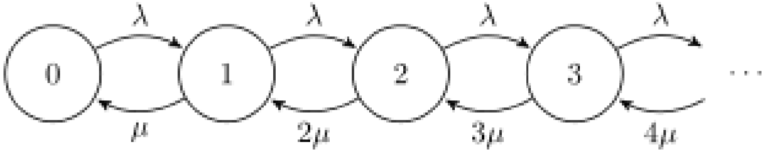

Fig. 1. The state transition diagram for M/M/∞ queueing model

Thus the $M/M/\infty$ queueing model with the following rate:

$$\begin{cases} \lambda_k = \lambda, \\ \mu_k = k\mu, \end{cases} \quad k = 0, 1, 2, \ldots \tag{14}$$

where λ_k and μ_k is the arrival rate and departure rate in state k, which is the state of the M/M/∞ queueing model, respectively.

Then, the steady state probabilities $P_{k,j}$ is given by

$$P_{k,j} = \left(e^{-\frac{A_{j-1}}{\xi}} - e^{-\frac{A_j}{\xi}} \right) e^{-\frac{\lambda}{\mu}} \frac{\left(\frac{\lambda}{\mu}\right)^k}{k!}, \quad k \ge 0 \tag{15}$$

Like [16], we assume that the interference level is constant during a bit duration Δt. We also assume the interference levels associated with consecutive symbols are neighboring states. The number of interfering packets will increase, decrease or remain the same during the bit duration Δt. Therefore, suppose that at the i-th bit in a packet, there are k interfering packets, there are possible k-1, k, k+1 interference packets at the (i-1)-th bit. Different from the previous with throughput analysis in AWGN channels, the DS CDMA/unslotted ALOHA system in Rayleigh fading we proposed, has an additional parameter - channel state j. The channel states of the FSMC will downward across, upward across or remain the same during the bit duration Δt. Therefore, suppose that the channel state is A_j at the i-th bit in a packet, , the state is possible A_{j-1}, A_j, A_{j+1} at the (i-1)-th bit according to the transition probability $h_{i,j}$. The state transition diagram of the proposed system is two-dimensional and shown in **Fig. 2**. Note that the bit duration Δt is very small due to high data rate, so the probability having more than one interferer added from one symbol duration to the next is close to zero.

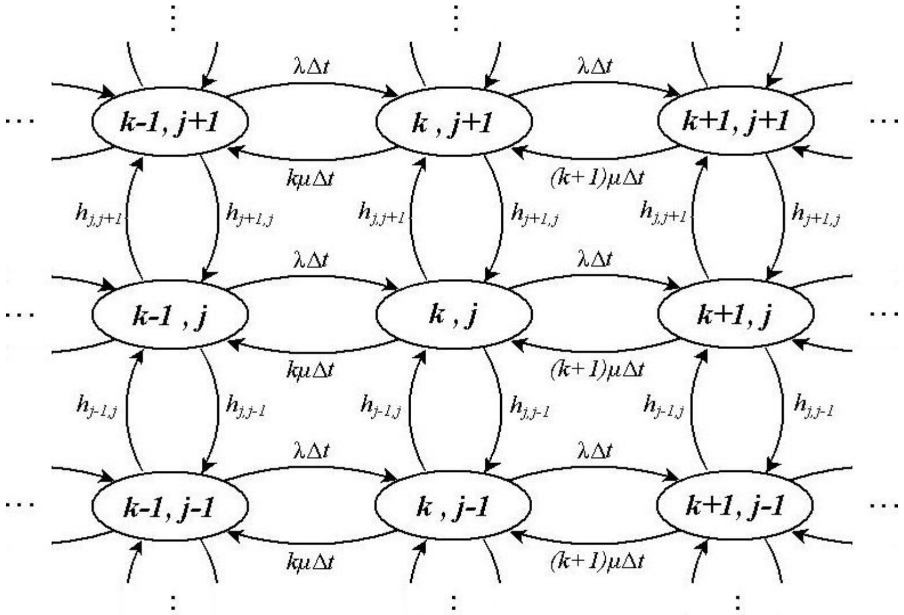

Fig. 2. The state transition diagram of DS CDMA/unslotted ALOHA system for variable message length and one user class with Rayleigh fading FSMC model

Define $P_s(k, j, i)$ as the probability of the following: the number interfering packets becomes *k* on the *i*-th bit, the fading channel is in the state *j* on the *i*-th bit and the packet transmitted successfully from the first bit to the (*i*-1)-th bit. According, the state transits during the bit duration Δt and the $P_s(k, j, i)$ is calculated recursively as follows:

$$\begin{aligned} P_s(k, j, i) = \sum_{j'=j-1}^{j+1} [&P_s(k, j', i-1) \cdot (1 - \lambda\Delta t - k\mu\Delta t) \cdot (1 - P_b(k, j')) \cdot h_{j',j} \\ &+ P_s(k-1, j', i-1) \cdot (\lambda\Delta t) \cdot (1 - P_b(k-1, j')) \cdot h_{j',j} \\ &+ P_s(k+1, j', i-1) \cdot ((k+1)\mu\Delta t) \cdot (1 - P_b(k+1, j')) \cdot h_{j',j}] \end{aligned} \tag{16}$$

The initial condition is given by

$$P_s(k, j, 1) = P_{k,j}, \quad k \geq 0, i = 2, \cdots, L. \tag{17}$$

Therefore, the packet success probability Q is given as following:

$$Q = \sum_{k=0}^{\infty} \sum_{j=1}^{M} P_s(k, j, L)(1 - P_b(k, j)) \tag{18}$$

Then, the throughput S is given as follows:

$$S = G \times Q \tag{19}$$

4.3 Proposed Throughput Analysis for Variable Message Length and Two User Classes (3D Markov Process)

Now we further divide users into two user classes. k_1 is number of interference of the *i*-th bit in class 1, k_2 is number of interference of the *i*-th bit in class 2 and $P_{s,n}(e, k_n, j, i)$ is probability of class n. The departure rates of class 1 and 2 messages are derived as:

$$\mu_1 = \frac{k_1}{T_p} \text{ and } \mu_2 = \frac{k_2}{T_p} \tag{20}$$

Also, the arrival rate of class messages is obtained as:

$$\lambda_n = \frac{G_n}{T_P \cdot \overline{B_n}} \quad , n = 1,2 \tag{21}$$

where $\overline{B_n}$ is average number of packets in a class n message.

Define $P_S^{'}(e,k_1,k_2,j,i)$ as the probability of the following: the number of interfering packets become k_1 and k_2 on the *i*-th bit, the SNR of FSMC fading channel is in state *j* on the *i*-th bit and the first (i-1) bits has *e* bit errors in the transmitted packet.$P_S^{'}(e,k_1,k_2,j,i)$ is calculated recursively as follows:

$$
\begin{aligned}
&P_S(e,k_1,k_2,j,i)=\sum_{j'=j-1}^{j+1}\\
&[\,P_S(e-1,k_1,k_2,j,i-1)\cdot\left(1-P_{tr.1}\lambda_1\Delta t-P_{tr.2}\lambda_2\Delta t-k_1\mu_1\Delta t-k_2\mu_2\Delta t\right)\cdot P_b(k_1+k_2,j')\cdot h_{j',j}\\
&+P_S(e-1,k_1-1,k_2,j,i-1)\cdot P_{tr,1}\lambda_1\Delta t\cdot P_b(k_1+k_2-1,j')\cdot h_{j',j}\\
&+P_S(e-1,k_1,k_2-1,j,i-1)\cdot P_{tr,2}\lambda_2\Delta t\cdot P_b(k_1+k_2-1,j')\cdot h_{j',j}\\
&+P_S(e-1,k_1+1,k_2,j,i-1)\cdot \mu_1 k_1\Delta t\cdot P_b(k_1+k_2+1,j')\cdot h_{j',j}\\
&+P_S(e-1,k_1,k_2+1,j,i-1)\cdot \mu_2 k_2\Delta t\cdot P_b k_1+k_2+1,j')\cdot h_{j',j}\\
&+P_S(e,k_1,k_2,j,i-1)\cdot\left(1-P_{tr.1}\lambda_1\Delta t-P_{tr.2}\lambda_2\Delta t-k_1\mu_1\Delta t-k_2\mu_2\Delta t\right)\cdot(1-P_b(k_1+k_2-1,j'))\cdot h_{j',j}\\
&+P_S(e,k_1-1,k_2,j,i-1)\cdot P_{tr,1}\lambda_1\Delta t\cdot(1-P_b(k_1+k_2-1,j'))\cdot h_{j',j}\\
&+P_S(e,k_1,k_2-1,j,i-1)\cdot P_{tr,2}\lambda_2\Delta t\cdot(1-P_b(k_1+k_2-1,j'))\cdot h_{j',j}\\
&+P_S(e,k_1+1,k_2,j,i-1)\cdot \mu_1 k_{1,i-1}\Delta t\cdot(1-P_b(k_1+k_2+1,j'))\cdot h_{j',j}\\
&+P_S(e,k_1,k_2+1,j,i-1)\cdot \mu_2 k_{2,i-1}\Delta t\cdot(1-P_b(k_1+k_2+1,j'))\cdot h_{j',j}\,]
\end{aligned}
\qquad (22)
$$

The first five terms in (22) are the probabilities that the first (*i*-2)th bits have*e-1* bit errors and the (*i*-1)th bit is also in error. The other terms in (22)are the probabilities that the first (*i* -2) th bits have *e* bit errors and the (i-1)th bit is correct.

The initial condition is given by:

$$
\begin{aligned}
&P_S\left(e=0,k_1,k_2,j,i\right)=\sum_{j'=j-1}^{j+1}\\
&[P_{ne}(k_1,k_2,j,i-1)\cdot\left(1-P_{tr.1}\lambda_1\Delta t-P_{tr.2}\lambda_2\Delta t-k_1\mu_1\Delta t-k_2\mu_2\Delta t\right)\cdot P_b(k_1+k_2,j')\cdot h_{j',j}\\
&+P_{ne}(k_1-1,k_2,j,i-1)\cdot P_{tr,1}\lambda_1\Delta t\cdot P_b(k_1+k_2-1,j')\cdot h_{j',j}\\
&+P_{ne}(k_1,k_2-1,j,i-1)\cdot P_{tr,2}\lambda_2\Delta t\cdot P_b(k_1+k_2-1,j')\cdot h_{j',j}\\
&+P_{ne}(k_1+1,k_2,j,i-1)\cdot \mu_1 k_1\Delta t\cdot P_b(k_1+k_2+1,j')\cdot h_{j',j}\\
&+P_{ne}(k_1,k_2+1,j,i-1)\cdot \mu_2 k_2\Delta t\cdot P_b k_1+k_2+1,j')\cdot h_{j',j}\,]
\end{aligned}
\qquad (23)
$$

where

$$
P_{ne}(k_1,k_2,j,1)=P_{k_1,k_2,j}=(e^{\frac{A_{j-1}}{\xi}}-e^{\frac{A_j}{\xi}})\cdot e^{-\frac{\lambda_1}{\mu_1}}\frac{(\frac{\lambda_1}{\mu_1})^{k_1}}{k_1!}\cdot e^{-\frac{\lambda_2}{\mu_2}}\frac{(\frac{\lambda_2}{\mu_2})^{k_2}}{k_2!}
$$

$$
k_1=0,1,2,\ldots\quad ,k_2=0,1,2,\ldots\quad ,i=1,2,\ldots,L\quad ,j=0,1,\ldots,M-1
$$

Therefore, the packet success probability *Q’* is given as following:

$$Q^{'} = \sum_{k_1=0}^{\infty}\sum_{k_2=0}^{\infty}\sum_{j=0}^{M-1}\left[\sum_{e=0}^{t-1} P_S(e,k_1,k_2,j,L) + P_S(t,k_1,k_2,j,L)\cdot(1-P_b(k_1+k_2))\right] \quad (24)$$

where *t* is the maximum number of correctable bits per packet by using error correction codes.

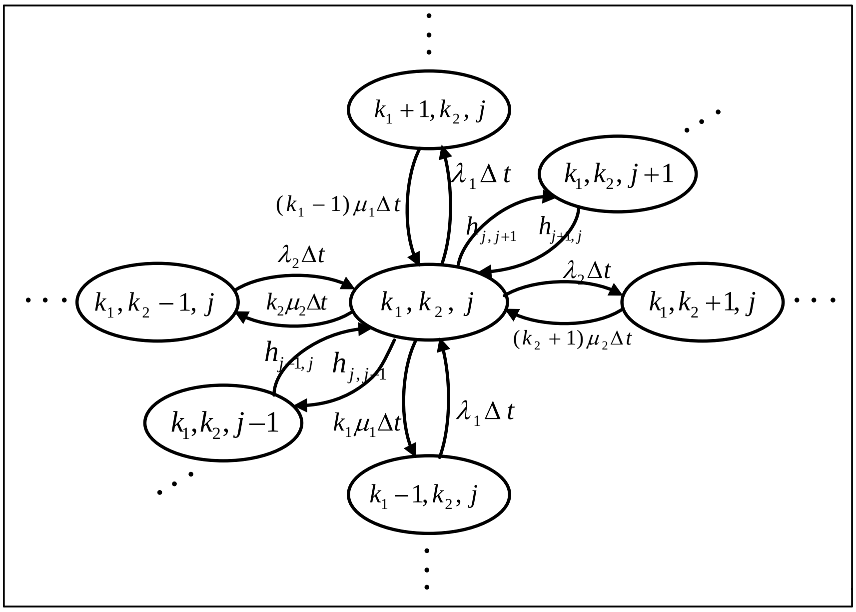

Fig. 3. The state transition diagram of DS CDMA/unslotted ALOHA system for variable message length and two user classes with Rayleigh fading FSMC model

Then, the throughput of two user classes S is given as follows:

$$S_n = \frac{L-2t}{L}\cdot G_n \cdot Q^{'} \quad (25)$$

where (L-2t)/L is the code rate of the error correction code

$$S_{total} = S_1 + S_2 \quad (26)$$

where S_n is throughput of class n, S_{total} is throughput of whole system.

The normalized (per unit bandwidth) throughput of two user classes S_{norm} is given as following:

$$S_{norm} = \frac{S}{N}\cdot\frac{L}{T_p} \quad [bits/Hz/s] \quad (27)$$

where N is the spreading codes length and also the bandwidth expansion factor, and L/Tp is to convert packets/packet duration to bits/s because one packet has L bits and the packet duration is Tp.

5. The Simulation And Numerical Result

We simulate DS CDMA/unslotted ALOHA system using binary phase-shift keying (BPSK) modulation, spreading code length (processing gain)N=30,the packet length L = 512 bits, the data rate $R = 9.6\,\mathrm{k}$ bps. We set average length of messages is 5 for one user classes, same as [17]. Then, we set the average length of class 1 messages is 7 and class 2 messages is 5 for two user classes, same as [18][19]. The number of SNR states of FSMC channel model is 8. The maximum Doppler frequency shift Fd is 10, 50 and 100 Hz. Because FSMC state usually over two, we chose 8. According to [32], they analyze 3 to 10 states for different modulations so we chose the 8 for our system. In **Figs. 4-12**, we use error correction code, and the number of correctable bits is 6, 8 and 10.

Figs. 4-6 shows that the simulation and numerical result of the proposed model versus the various Doppler frequency shift Fd with the number of correctable bit t=6, 8 and 10, respectively. They first show that the throughput decreases as the Doppler frequency shift increases if the number of correctable bit t is fixed. We can observe another thing comparing Figs. 4-6: for Fd=10, the peak throughput is 4.5, 5.2, 6.0, for t=6, 8, 10, respectively; for Fd=50, the peak throughput is 3.3, 4.0, 4.8, for t=6, 8, 10, respectively; for Fd=100, the peak throughput is 2.7, 3.4, 4.2 for t=6, 8, 10, respectively. Therefore, the throughput increases as the number of correctable bit t increases if the Doppler frequency shift is fixed. This is because error correction codes convert some unsuccessful packet transmission in the successful ones. We also observe that the system throughput decreases as Doppler frequency shift Fd increases. This is because the probability of the received SNR state crosses down the poor SNR state increases as Doppler frequency shift Fd increases.

Figs. 7-9 are DS/CDMA unslotted ALOHA with variable message length for two user classes in Rayleigh fading FSMC model without access control. That is $P_{tr,n}$ =1. In **Fig. 7**, for Fd=10, when message arrival per packet duration over 1.0, system throughput will decrease from the peak throughput 5.9. We find similar phenomena in different Doppler frequency offsets in **Figs. 8-9**. In **Fig. 8**, for Fd=50, when message arrival per packet duration over 0.9, system throughput will decrease from the peak throughput 4.7. In **Fig. 9**, for Fd=100, when message arrival per packet duration over 0.8, system throughput will decrease from the peak throughput 4.2.

The access control in (10) can maintain total throughout at maximum when high message arrival, as shown in **Figs. 10-12**. For example, in Fig. 10, for Fd=10, when message arrival per packet duration is over 1.0, the total throughput *remains* at the peak 5.9 when message arrival per packet duration is over 1.0. For comparison, in **Fig. 7**, the total throughput *drops* from the peak 5.9 when message arrival per packet duration is over 1.0..

For each simulation point in **Fig. 4-12**, the number of packets simulated is 500,000. We can see the simulation and numerical results are very close, so the number of packets simulated is sufficient to ensure high degree of confidence level.

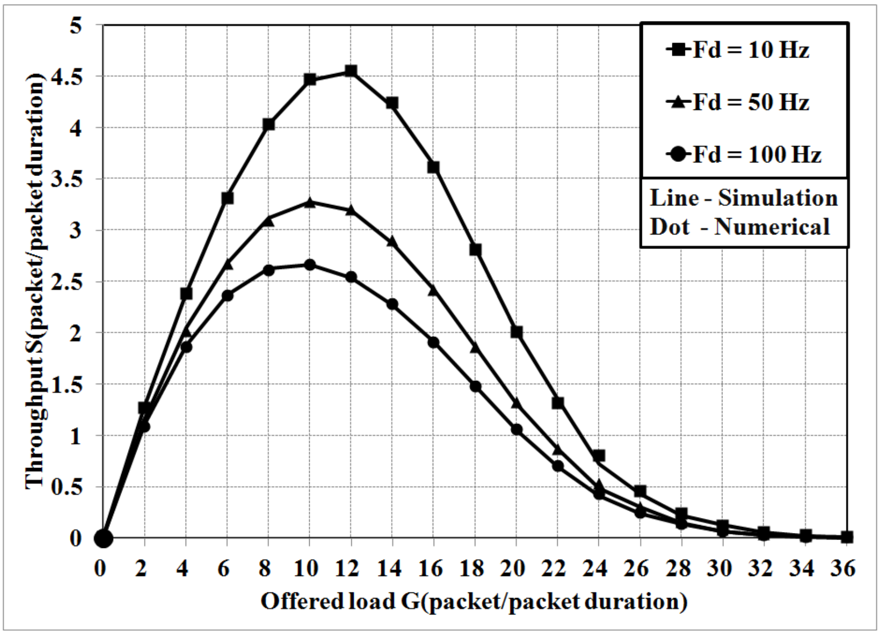

Fig. 4. The throughput versus SNR=10, Fd=10, 50 and 100, t=6 with variable message length for one user class

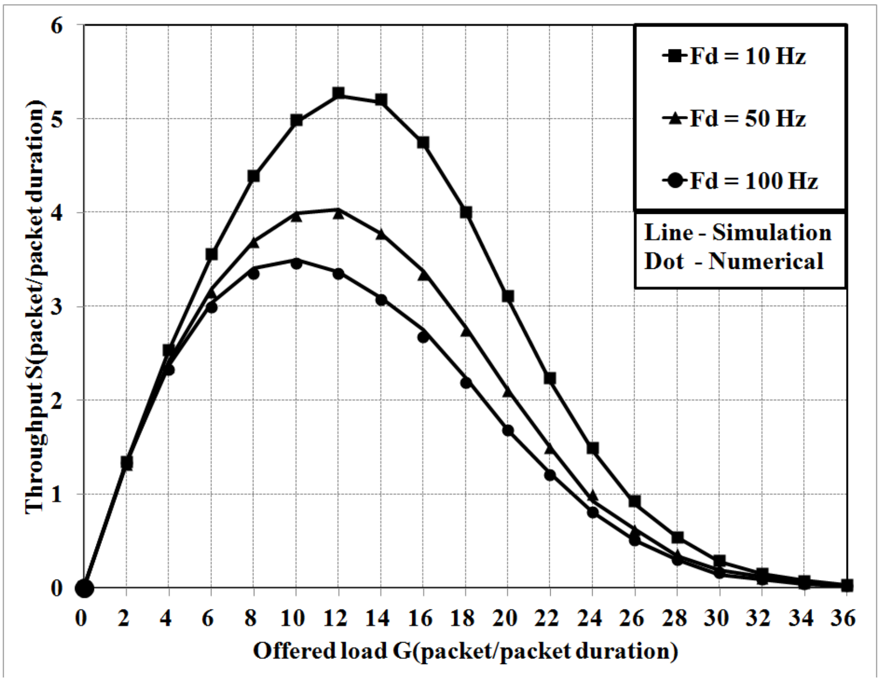

Fig. 5. The throughput versus SNR=10, Fd=10, 50 and 100, t=8 with variable message length for one user class

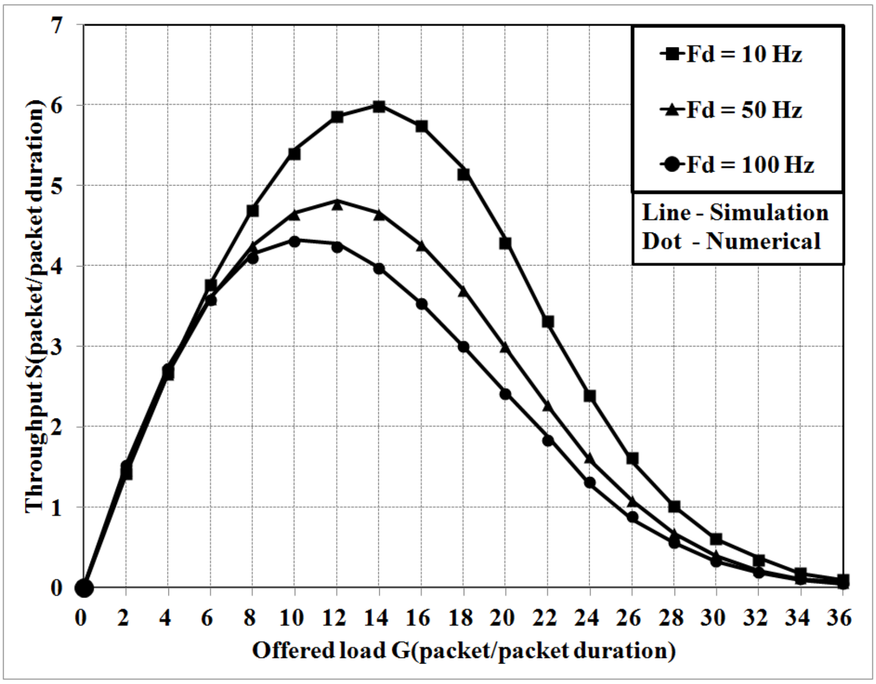

Fig. 6. The throughput versus SNR=10, Fd=10, 50 and 100, t=10 with variable message length for one user class

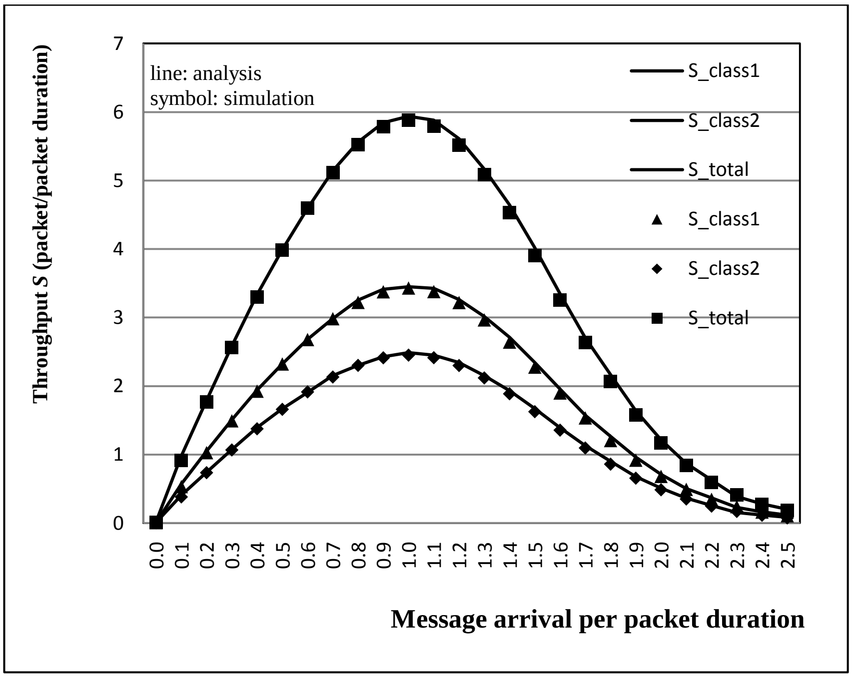

Fig. 7. Simulation and numerical result of SNR=15dB without access control, Fd=10Hz, t=6 with variable message length for two user classes

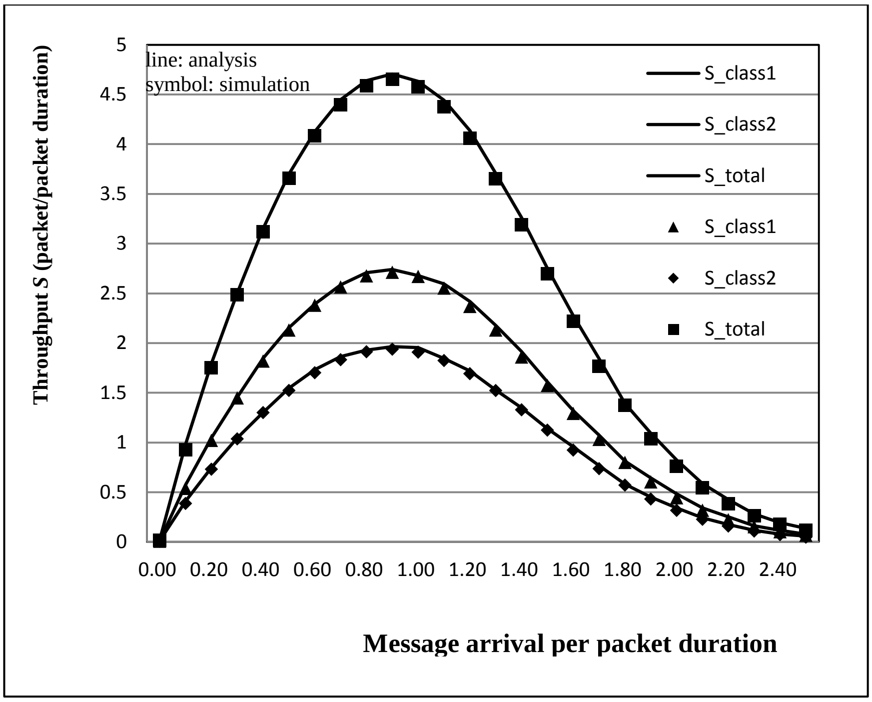

Fig. 8. Simulation and numerical result of SNR=15dB without access control, Fd=50Hz, t=6 with variable message length for two user classes

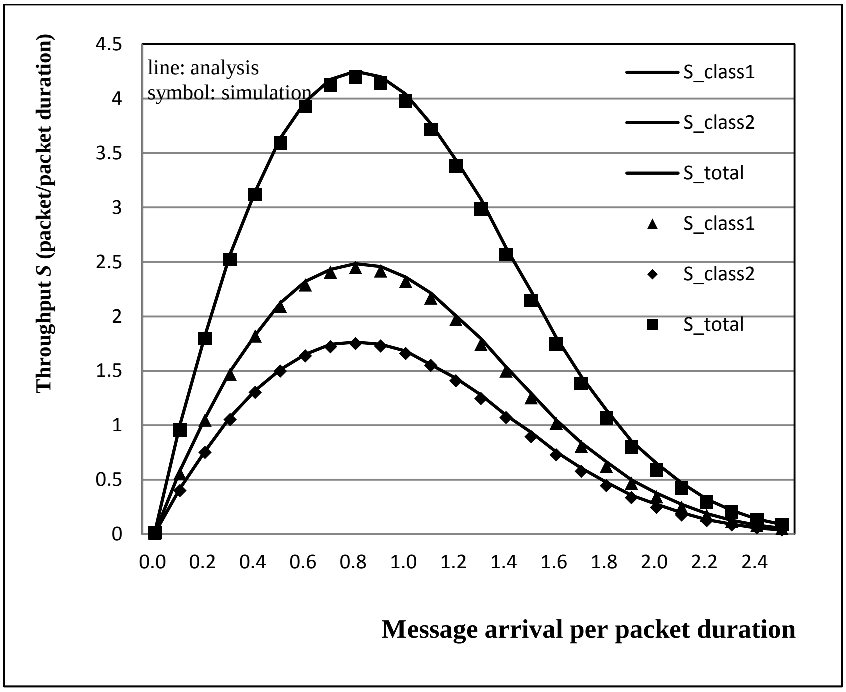

Fig. 9. Simulation and numerical result of SNR=15dB without access control, Fd=100Hz, t=6 with variable message length for two user classes

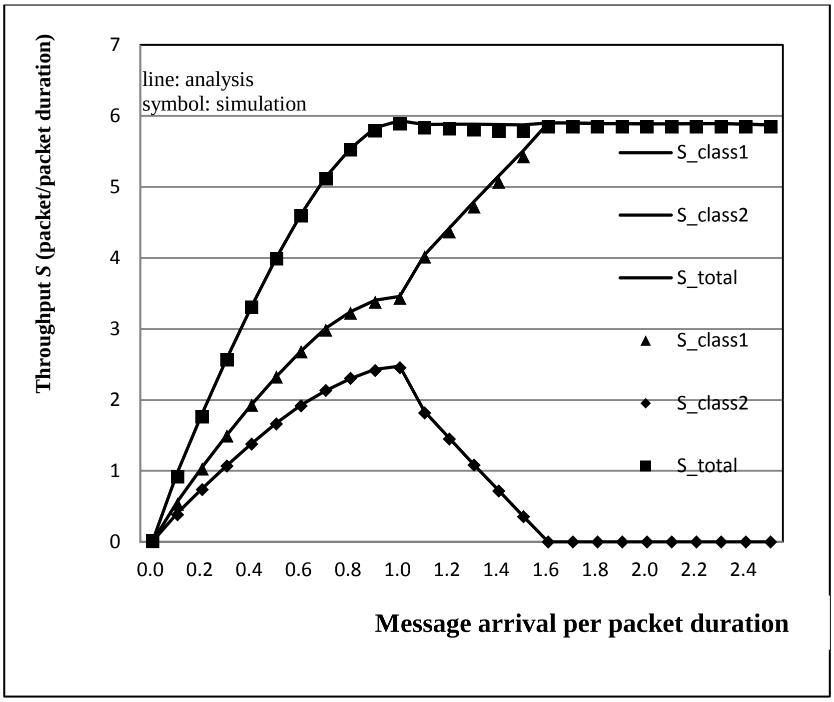

Fig. 10. Simulation and numerical result of SNR=15dB with access control, Fd=10Hz, t=6 with variable message length for two user classes

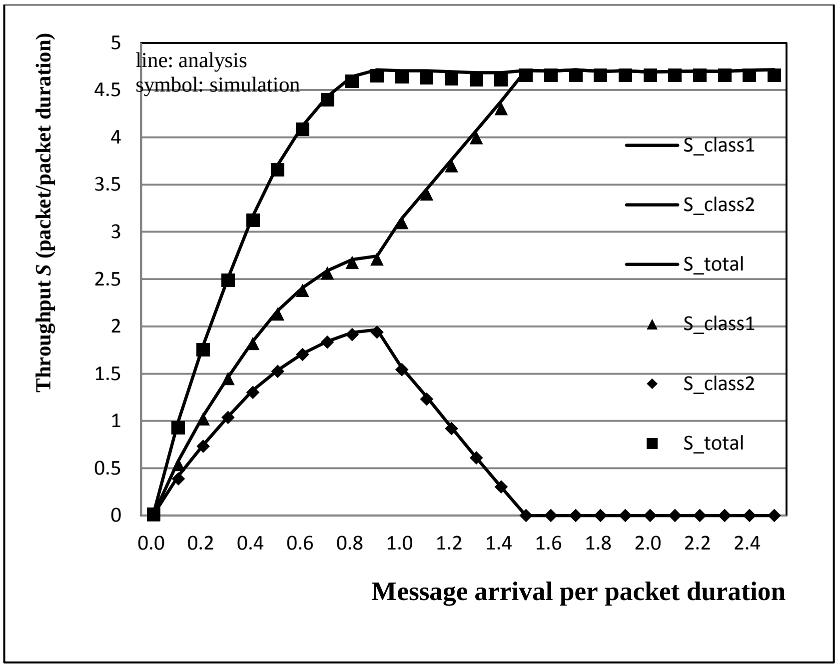

Fig. 11. Simulation and numerical result of SNR=15dB with access control, Fd=50Hz, t=6with variable message length for two user classes

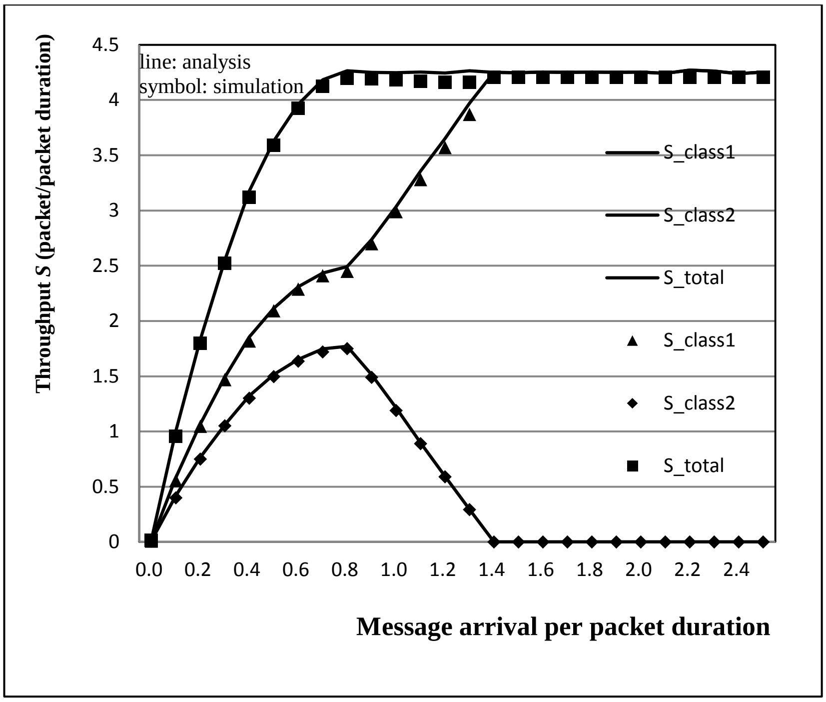

Fig. 12. Simulation and numerical result of SNR=15dB with access control, Fd=100Hz, t=6with variable message length for two user classes

6. Conclusion

In previous papers, they mostly consider the non-fading channels. In the papers[21][22][23], the authors consider only that the channel coefficient of Rayleigh fading was the same in the whole packet, which is not realistic. In [24], we proposed the FSMC to analyze throughput performance of the uncoded DS CDMA unslotted ALOHA networks with fixed length data traffic and one user class. The channel gain as well as multiple access interference can vary from symbol by symbol. In this paper, we propose the FSMC to analyze throughput performance of the coded DS CDMA unslotted ALOHA systems for *variable* message length with one or *two* user classes, and access control in mobile channels. Compared to [24], we add channel coding, variable length data traffic, and two user classes in this paper. In this paper, we analyze the effect of channel coefficients and the effect of Doppler frequency shift symbol-by-symbols. We can observe that the system throughput decreases as the Fd increases. The proposed use of FSMC allows us to model the symbol-by symbol SNR variation in mobile channels. The numerical and simulation results both show that our proposed two user class network can reach maximum system throughput in high offered load.

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