Performance Study of Piggybacked CDMA/PRMA HAP System

Yaser A. Salem

Abstract*— This paper introduces a multiple access scheme called CDMA/PRMA with Piggybacked Reservation, which employ High Altitude Platforms (HAPs) as innovative wireless base station with balanced cell coverage, to achieve higher statistical multiplexing efficiency in the mixed CBR / VBR /ABR (constant, variable, and available bit rate) traffic environment. The idea is to use HAP as mobile communication assisted system with almost equal paths to communication nodes, while reducing signal impairment. The adopted scheme exploits reservation access mechanism. The reservation is assigned in a separate slice of the frame (reservation mini frame) while the rest of the frame is allotted to the communication traffic. The second level exploits the piggybacked reservation with multimode video encoder to deal with the dynamic nature of VBR traffic in order to increase the channel access efficiency. The expediency of the adopted schemes is insured through the simulation of an isolated cell environment. The obtained results indicated that, a substantial increase in the number of heterogeneous users is attained within the intended QoS level.

***Index Terms*—CDMA, PRMA, HAPs, Stratospheric, Communication.**

I. INTRODUCTION

The enormous and endless demand for broadband communications is a challenge that many people are trying to solve. Commercial data providers continue to research ways to bring high-speed data communications services to the customers in both cities and rural areas. Current infrastructures are a collage of terrestrial (e.g. wireless, cable, and traditional telephone lines) and satellite networks whose coverage does not span the entire globe or is problematic or prohibitively expensive to access. Out of this industry sector, the concept has grown of providing wireless broadband communications via High Altitude Platforms (HAPs). This concept has potential for solving some of the modern telecommunications challenges such as ubiquitous wireless communications, and the need for rapidly deployable high-speed data communications in the vast growing telecommunication market[1..10].

HAPs are quasi-stationary airships or UAV operating within the stratospheric layer, due to the capability of LOS (line of sight) communications are as in the satellite systems, but at lower propagation loss due to the relatively lower altitudes (20-60 km) , therefore, it combine the advantages of both terrestrial and satellite communications[13]. HAP networks offer advantages of reconfigurable and dynamic resource allocation, coupled with flexibility and rapid deployment.).

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Directing beams toward intended locations is obtained by using either spot beam antennas or a two-dimensional phased array that cover the desired cells on the earth surface [15, 16, 17]. Many literatures [18, 19] adopted CDMA/PRMA (Code Division Multiple Access / Packet Reservation Multiple Access), and its implementation is being discussed with regard to the satellite component of the UMTS network (S-UMTS) [21, 22, 23, 24]. This protocol incorporates PRMA in the CDMA environment in order to support bursty traffic characteristics, such as packetized voice when applying voice activity detection. The PRMA scheme is based on Time Division Multiple Access (TDMA) and combines random access with slot reservation. In the adopted scheme the access process is accomplished by making a reservation in a dedicated reservation slots in a separate portion of the frame, while the rest of the frame is reserved in accordance with the reservation slots. Combining it with the characteristics of CDMA more efficient radio packet communication systems can be achieved, since each slot can support more than one simultaneously transmitted packets, limited by multiple access interference (MAI) [24, 26, 27]. A two levels of reservation is introduced to achieve optimum performance for real time video communications and to increase the capacity of the mobile networks. In order to achieve this goal, two assumptions are employed. The first assumption is to incorporate two levels of Reservations. The first level is using the ALOHA reservation in the reservation period [28]. The second level employs the piggybacked reservation to deal with the dynamic nature of VBR (variable bit rate) traffic in order to increase the multiplexing efficiency [29]. The second assumption is employing a multimode encoder equipped with a buffer at the user's mobile terminal [14]. The buffer stores statistical peaks of the coding rate by provisionally storing excess video packets. An exigency flag is used to monitor the expiration of packets in the video buffer [30], in case of exceeding a certain threshold, the encoder turns to a lower coding rate but with less quality to avoid buffer overflow. The video multimode encoder ranges from 16kbps to 128kbps.

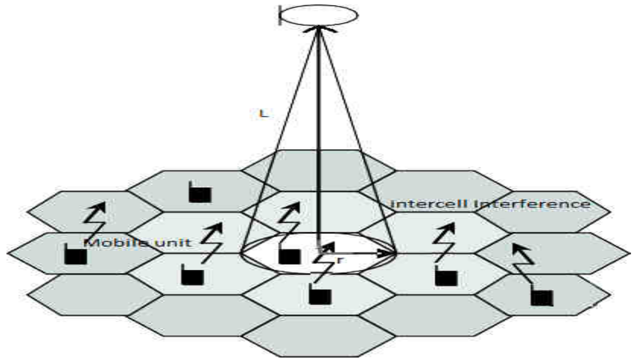

Fig. 1 HAPs interference geometry.

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II. SYSTEM DESCRIPTION

A. HAP SYSTEM

HAP stations may be used as base stations within the terrestrial area [31]. It employ a phase array antenna to project spot beams for telecommunication services. The spot beams spread over the coverage area, in a pattern similar to that created by a traditional cellular system. In our scheme CDMA payload is carried out by the HAP, at an altitude of 22-25 Km above the service area. It is assumed that, HAP system is kept stationary with regard to the ground surface. Due to its low altitude, the effect of the earth's curvature is neglected, and each spot beam cover an equally tessellated service area of radius r [34], i.e. macrocell. The service area has r = 517 Km for an altitude of 21 Km [33]. For the studying case, perfect power control is employed, mobile users are uniformly distributed and, the signals from all mobile users in a given cell arrive at the HAP with the same power.

B. TRAFFIC MODELS

1) Frames and Slots: As shown in figure 1, the time scale is organized into frames, each containing a two types of time slots. The frame rate is matching the rate of generation of voice packets. All mobile units transmit their packets such that they arrive to the HAP station within the slot boundaries. In compared with to conventional PRMA, terminals do not classify slots as either "reserved" or "available," as the channel access for contending terminals are only in the reservation minislots and is accessed through dynamic permission probabilities Pp.

2) *Reservation Mode:* A terminal that generates periodic data switches from contention to reservation mode as soon as the HAP station acknowledges the reception of successful reservation packet, and stays in reservation mode until the last packet of the current spurt is transmitted. The HAP station conceder all the packets sent from periodic terminals in each slot (which can be achieved as long as the headers are detected correctly) , and compute the utter permission probability for the next frame with the channel access function, and then transmits this value in the feedback to all mobile units.

3) *Collisions:* collisions is controlled to be only on the reservation period and at the moment two or more terminals send reservation packets using the same code and in the same minislot. Considering that, in the case of DS/CDMA, collisions in the proper sense of the word as in PRMA, is no longer accounted as one slot supports more than one simultaneous transmitter. On the other hand, the packet success probability within a specified slot is accounted on the number of simultaneously transmitted packets, the used forward error correction (FEC) coding, and the spreading factor S_f.

4) *Contention and Packet Dropping*: In order to transmit a reservation packet, terminals in contention phase have to get the feedback of utter permission probability related to their type of service. They are permitted to transmit a packet if the random number generated in their mobile units is less than or equal to the feedback of permission probability broadcast from the HAP.

Mobile units keep trying to transmit reservation packet in the reservation period until the base station acknowledges successful allocation of the packet. The maximum packet holding time, D_{max} is determined by delay constraints on real time type of communication. If a terminal drops the first traffic packet due to expiration, it continues to contend for a reservation until dropped all packets or gain a reservation. It lose additional packets as their holding times exceed certain value D_{max}.

Terminals in transmission mode, store packets infinitely while they contend for reservation ($D_{max} = \infty$).

Instead of wasting another channel in sending empty packet at the end of spurt, Mobile terminals use piggybacked field at the end of final packet to tell HAP that this packet is the last one in its buffer.

C. Medium access channels model

It is well known that the CDMA system is an interference-limited system. Reduced interference variance leads to a lower outage probability of the system, thus to increase capacity. In the cellular system under consideration, DS/CDMA with spreading sequence of length *sf* chips per bit is assumed, and the neighboring cells use different frequencies.

By using different frequency bands in neighboring cells we resolve inter cell interference problem [35]. A widely used approximation to determine the BER performance on CDMA channels is the standard Gaussian approximation (SGA)[36].

Assuming that the multiple access interference MAI is Gaussian distributed, and using BPSK modulation/demodulation and a simple correlation receiver, the bit error probability, P_e, can be obtained from:

$$P_e \approx Q\left(\overline{SNR}\right). \tag{1}$$

Where,

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-u^2/2} du \;. \tag{2}$$

In the above equations the average signal-to-noise ratio for the *i*th packet in the case of unequal power reception when considering a single-cell system can be written as follow [37]:

$$\overline{SNR} = \sqrt{\frac{P_i}{(3sf)^{-1} \sum_{\substack{k=1 \\ k \neq i}}^{K} P_k + N_0/2T}} \;. \tag{3}$$

Where, the received power levels "P_i" ($i = 1, 2, \ldots k$) from K simultaneous transmitting terminals in a given slot, T is the data bit duration, ($N_o/2$) is the two-sided spectral density of additive white Gaussian noise (AWGN) channel, and P_k is the power level of the *k*th user.

The case of no intercell interference means, the HAP directional antenna transmit different frequencies in neighboring cells. Assuming that the system has a perfect power control, so the signal emitted by every transmitter is received by the HAP with P_0 power level, by neglecting "N_o"[40] we have:

$$\overline{SNR} = \sqrt{\frac{P_0}{\frac{(K-1)P_0}{3sf}}} = \sqrt{\frac{3sf}{K-1}} \;. \tag{4}$$

Assuming that packets of length L bit are transmitted over a memoryless binary symmetric communication channel with average probability of data bit success ($Q_e = 1 - P_e$) and employing a block code with forward error correction *t*

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capable of correcting *t* errors, the packet success probability Q_E can be derived from:

$$Q_E = \sum_{i=0}^{t} C_L^i \left(1-Q_e\right)^i \left(Q_e\right)^{L-i} \quad . \tag{5}$$

D. Multicell System

In the following subsection, we study the adopted CDMA/PRMA system performance in multicell environment and a realistic distance dependent propagation coefficient model. The distance dependent model considered here is motivated by signal attenuation measurements [38-39] which show that the variation of path loss (in dB) with distance (on a log scale) is described by piecewise linear curves with multiple breakpoints. This means that the propagation loss coefficient is not constant over the entire service area but that it increases with the distance between base station and remote unit [40]. We treat the intercell interference as a function of propagation coefficient γ on the performance of the adopted scheme.

E. The Multi-Cell Interference

The CDMA protocol allows each cell to use the same frequency band distributed by HAP antenna array. In a multicell environment, capacity evaluation is carried out according to the total interference from the consider cell and that originated from other surrounded cells. We consider a regular hexagonal cell layout with a pointed beam to the center of each cell. The average value of an intercell interference level can be obtained from the procedure developed in [39] and [41]. When considering a path-loss law with a distance-independent path-loss exponent, for equally loaded cells, the normalized intercell interference for unit traffic per

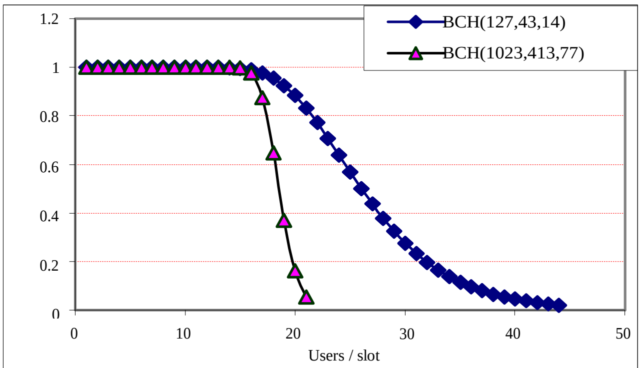

Fig. 2 Packet success probability for sf=12

cell Iintercell depends only on the value of path-loss exponent.

For path-loss exponent γ = 3 and γ = 4, Iintercell (unit traffic/cell) amounts to 0.749 and 0.37, respectively (see [40]).

For a hexagonal cellular structure, it is possible to compute the total interference received from all the cells in the system. System assumptions:

1- We have a multicell system with R+1 equally loaded cells, where R is the number of adjacent cells, and each has K active users (contending and reserving) terminals. The average SNR for conceding cell (0) when perfect power control is applied, can be written as follows [84]:

$$\overline{SNR} = \sqrt{\frac{3P_0 N}{(K-1)P_0 + \sum_{k=1}^{k}\sum_{i=1}^{R} P_{(k,i)0}}} \tag{6}$$

Where P0 denotes the desired signal power level while (k-1) P0, and $\sum_{k=1}^{k}\sum_{i=1}^{R} P_{(k,i)0}$ denote the Intracell and Intercell interference, respectively. Note that the effect of the AWGN is neglected in the above equation due to the consideration of the intercell interference. Thus, the Bit Error Probability Pe can be derived in multicell environments.

2- The multiple access interference MAI is Gaussian distributed, and a simple correlation receiver using BPSK odulation/demodulation and, Pe can be calculated from equations 1 and 2.

3- The communication channel is memoryless binary symmetric with average probability of data bit success (Qe= 1- Pe) when packets of length L is transmitted.

4- Employing a block code with forward error correction t, therefor, the packet success probability QE can be derived from equation (5).

Thus, $\sum_{k=1}^{k}\sum_{i=1}^{R} P_{(k,i)0}$ can be substituted by.

$$\sum_{k=1}^{k}\sum_{i=1}^{R} P_{(k,i)0} = P_0 . I_{Intercell} \cdot \frac{C.\alpha_s}{O}$$

Hence, the average SNR for test cell (0) can be written as,

$$\overline{SNR} = \sqrt{\frac{3N}{(K-1) + I_{Intercell} \cdot \frac{C.\alpha_s}{O}}} \tag{7}$$

Where C represents the number of simultaneous conversations in each cell, and O is the number of slots per frame. Simulation results for the voice only system with γ=3 and γ=4 are depicted for the considered scheme.

III. PACKETS FORMAT

We have two types of transmitted packets,

1) Reservation packets

2) Service packets.

Each type of the transmitted packets has fixed length (L_R, L_S) bits, where L_R is the reservation packet length, and L_S is the length of the service packet. In general, each packet will contain some forward error correction to mitigate the effect of multi-packets transmitted within the same time slot, and the thermal noise. In the example used here, a *'t'* error correcting BCH code is used. Therefore *(L,M,t)* BCH-code [14] are considered for FEC where, *L* bits is the packet length after coding, and *M* bits is the message packet length before coding, while *t* is the number of correctable errors. The design parameters are setup as shown in table 1. PRMA frame consists of 20 time slots; the first slot is dedicated for reservation, and is divided into 8 minislots, while 19 slots are dedicated for traffic. Packet length before coding is 413bits, and after coding with a rate of 0.4 become 1023 bits. A

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spreading factor S_f of 12 is employed, so that the total CDMA channel rate becomes 12.275 Mcps. (1023,413,77) BCH code is considered for traffic FEC.

Reservation packet is of length 43 bits with 0.34 code rate, and 14 bit correctable error capability. (127,43,14) BCH code is considered for traffic FEC.

The appropriate number of simultaneous transmitting users within the slot that satisfy the limits of the packet success probability Q_E [k] for both reservation and traffic sub frame can be obtained by Substituting in equations (1-5) and are shown in figures. 6 and 7.

IV. FRAMES AND CHANNEL STRUCTURE

Frame Structure

The frame is represented in two dimensions, in time dimension, (TDMA), and in code dimension (CDMA).

The time dimension is divided into two periods.

1) Reservation period
2) Traffic period.

The reservation period is the (first or first and second) time slot, this time slot(s) is divided into mini-slots in the TDMA dimension while in the code dimension there is no assignment (the available codes are assigned for both TDMA periods, and the intersection between the two dimensions is called the channel.

By using R mini slots and K codes, the number of reservation channels $N_R = RK$, and in the traffic period, the number of service channels $N_S = SK$ where S is the number of traffic time slots. Active terminals use the reservation channels in the contention phase, by sending a reservation packet. Reservation packet mainly contains, the terminal ID, type of service (voice, video, data), plus other header information.

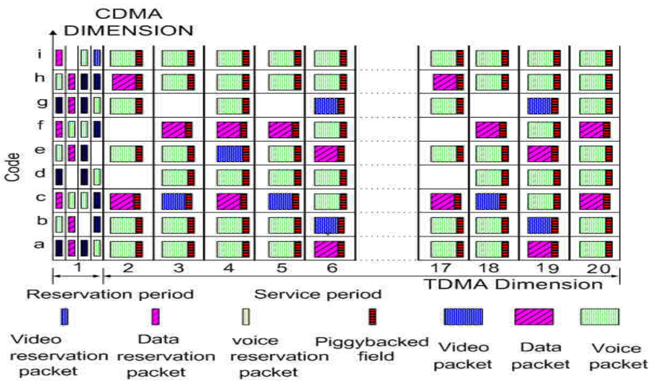

Fig. 3 Slots and frame structure for CDMA/PRMA with piggybacked reservation

As periodic source generates exactly a packet per frame, the amount of information per packet is $R_S\ T_F$ bits where R_S bit/sec is the source rate (voice), and T_F is the frame duration. Each traffic packet contain a header information H bits, the total packet length is $((R_S\ T_F + H)\ /r)$ bits.

Where r is the code rate for the traffic packet coder, and T_F sec is the frame duration.

The traffic channel carries $R_P\ T_F /r$ bits, where R_P bit/sec is the channel rate of the channel before coding and spreading.

Therefore, the number of time slots per frame O is given by:

$$O = \left\lfloor \frac{R_p T_f}{R_s T_f + H} \right\rfloor \quad (8)$$

Where $\lfloor \chi \rfloor$ is the largest integer $\leq$ X. The time slot duration $\tau = T_F / O$ *sec*.

The mobile terminal will be either silent or active. If it is active it will be in one of three-state Contention, Reservation, or Access. Any terminal can inter to contention mode if

1) It has packets to transmit
2) It has a valid permission probability.

In case of successful reservation, the base station dedicates the amount of channels suitable for this kind of service only if these amounts of channels are available, otherwise the mobile unit become in waiting state.

Terminals who have a packets and valid permission probability should contend only in the reservation period of the frame, while the method of reservation is in ALOHA basis.

Real times services (voice and video) are kept in a reservation state during their active period while their buffer is not empty. Data unit must contend for every packet and there is no reservation for data.

V. TRAFFIC PARAMETERS

Voice traffic

The speech source generates periods of talk sports and gaps by using speech activity detector SAD to differentiate between principles talk spurts (ON state) and principle gaps (OFF state). The ON and OFF Periods are assumed to have exponentially distributed Durations, which are statistically independent of each other. Voice packets are generated only during the ON Period. The mean duration of the talk-spurts and gaps are 1 sec and 1.35 sec respectively. Due to the robustness of voice conversation, speech messages can be reconstructed at the distention user with acceptable quality provided that the voice packet loss is less than 2%. In each talk spurt, the speech is sampled at 16 kb/sec, and Voice packets that suffer from a delay exceed 40 ms will be dropped. It is assumed that voice traffic is heavy load, and all voice terminals are active and in continuous conversation.

TABLE 1
Simulation Variables

Definition	Notation	Units	Values
CDMA Channel rate	R_c	Kb/s	12275
PRMA Channel rate after coding	R_{pc}	Kb/s	1023
PRMA Channel rate before coding	R_p	Kb/s	413
Number of Correctable bits	t_t	bit	77
Code rate	r		0.4
Spreading factor	sf		12
Path loss exponent	γ		3,4
Reservation minislot	N_{ms}	slot	8
Reservation packet length	L_r	bit	127
Traffic packet length	L_T	bit	1023
Number of Correctable bits (reser.)	t_r	bit	14
Voice source rate	R_{ss}	Kb/s	16
Video source rate (VBR)	R_{sv}	Kb/s	16- 128
Frame duration	T_f	ms	20
Slot duration	T_S	ms	1
Over head	H	bit	93
Speech activity detector			Slow
Maximum delay	D_{max}	ms	40
Permission probability speech	P_{Ps}		0.1-.9
Permission probability data	P_{Pd}		.01-.9
Permission probability video	P_{Pv}		0.1-.9
Number of voice users	M_s		Variable
Number of data users	M_d		Variable
Number of video users	M_v		Variable

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Data traffic

Each random data terminal can create at most new packet in one slot, where σ_d is the probability that there is a new packet in a slot, and is equipped with an infinite First-In-First-Out (FIFO) buffer to store delayed packets. Denote the average data bit rate by R_d and the data packet that has the same duration as voice packet is generated independently. Hence the mean bit rate of data terminal is:

$$R_d = \sigma_d R_S O. \qquad (9)$$

A constant data bit rate of 3.4 kb/sec is assumed for simulation, and data packets are originated from independent Poisson input stream with mean inter-arrival time equal to 0.02 sec.

Video traffic

Video traffic is represented here by a variable bit rate with exponentially distributed transmission time of a mean equal to 180sec. As shown in figures 4, any video terminal will be assigned first with one channel, and according to the amount of queued packets in its buffer, it can ask through the piggybacked field for additional channels up to 8 traffic channels (8 channels/frame). Piggybacked field is updated in each frame, and video terminal can keep the channels until the end of the current active period. For proper operation this traffic channels must be in different slots, but no matter to be with different codes. Many video compression techniques can be employed to increase video allocation in mobile networks. Due to the sophistication nature of the compressed video stream, a very low packet loss rate is required in order to construct the frames at the receiver end. So that video packet drop probability is set to be as small to meet this requirement. The instantaneous bit rate of video codec varies greatly depending on the video sequence complexity.

VI. PROTOCOL ASSUMPTIONS

It is assumed that:

Power control is perfect and all packets arrive from users within a given cell are received with the same power at the HAP.

All packets arrive to the HAP are synchronized, and a strong forward error correction FEC can correct all corrupted packets. So the packet loss are due to the fact that it last in queue more than maximum delay, while the user that wins a reservation couldn't find the intended number of channels, or the collision between reservation packets in the reservation period.

The flowchart that describe the reservation process is shown in figures 4, while the flowchart that represent the allocation process is depicted figure 5.

VII. SIMULATION RESULTS AND DISCUSSION

The performance of the network under the adopted protocol is investigated by using computer simulation that simulates the network under random event and with different permission probability for each class of service. Simulation parameters are shown in table 1. Performance control parameters are set as: 2% maximum voice packet drop probability, 0.1% video packet drop probability, and 300msec Maximum data average delay. Slot capacity is an important factor on studying the overall system capacity, increasing the number of simultaneous conversations results increasing of BER (Bit error rate), if the employed BCH code is not efficient in correcting corrupted packets, a poor voice quality or even a connection failure could be established. To insure that the overall performance is a result of medium access control protocol, packet success probability set to be .9 in the simulation program.

Simulation for voice only traffic was established with γ equal to 4 as standard assumption for mobile communication [84], and with γ equal to 3 as a more pessimistic assumption.

Average Signal to noise ratio is obtained by substituting in equation (9), and then by substituting in equation (1), the packet error probability P_e is obtained.

Figure 6 represent the packet success probability for reservation subframe when variable number of active users in a heavy path loss (γ=4), try to win a reservation in reservation minislot, while in figure 7 the packet success probability under the same condition but with path loss (γ=3).

By comparing the two figures, the probability of successful packet in the system with smaller exponent path loss is larger than that of higher path loss exponent.

From figures (8, 9), it is also noticed that, the probability of successful packets through the traffic period of the frame when γ=3 is higher than that when γ=4.

Simulation results are depicted in figure 10 under the condition of 0.9 permission probability. The capacity decrease due to intercell interference is obvious and the effect of propagation coefficient has a great impact on system capacity.

The capacity decrease compared to an isolated cell for γ = 4 is about 40%, while for γ=3 it is about 65% for voice packet loss probability equal to 1%. For voice packet loss probability equal to 2% the capacity decrease compared to an isolated cell for γ = 4 is about 37%, while for γ=3 it is about 64%

The network performance is also evaluated with different number of video users, in isolated cell and the effect of neighboring cells in multicell system with the variation of γ. From figure 11, It is noticed that the increase of simultaneous active video users accessing the network has a great effect on video packets drop probability, that is because each active user wins a reservation, has a big number of traffic packets that occupy the channel until he finish his session.

It is also noticed that, with increase of γ, the video packet drop probability increase as well.

From Fig. 11, it is noticed that, the increase of active data users has a significant effect on data average delay, so the number of active data users shouldn't increase more than 300 to protect data average delay from exceeding the limit of the 300 msec. The effect of γ is clearly affect the data packet average delay, when the system capacity is set to 300 users, increasing γ to 4, will result of increasing data average delay over 300 msec.

VIII. CONCLUSION

In this paper a scheduling algorithm piggybacked reservation PRMA/CDMA for HAP communication system is introduced and the performance promises with a great features. It inherits the good features from booth PRMA and DS-CDMA protocols. Higher capacity of different classes of users is achieved by using multi-slots reservation and more than one

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mini-slot per reservation slot. Utilization efficiency is increased with the constrained of the adopted QoS, compared with either CDMA or PRMA alone from advised HAP systems. Scheduling algorithm enhance network capacity compared with [18, 19]. HAP scheduling algorithm should have a lookup table for the available channels and the ability to distinguish the best code and time slot for better management of network resource, and to assign suitable permission probability for each class of service. Using two levels of reservation have a great improvement on video communications; however, it has a harming effect on data average delay.

Concentric Cell, and micro/Pico HAP cellular configurations with perfect power control techniques may also apply to get more utilization efficiency. Future research is required on the effect of imperfect power control and on synchronization aspects.

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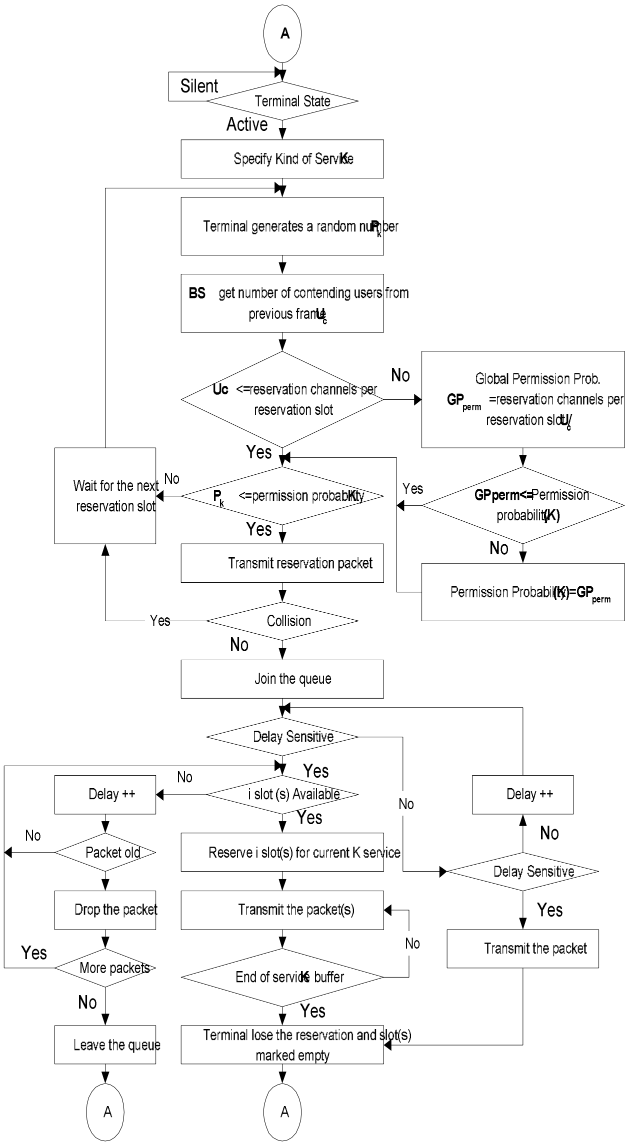

Fig. 4 flowchart for CDMA/PRMA with Piggybacked reservation

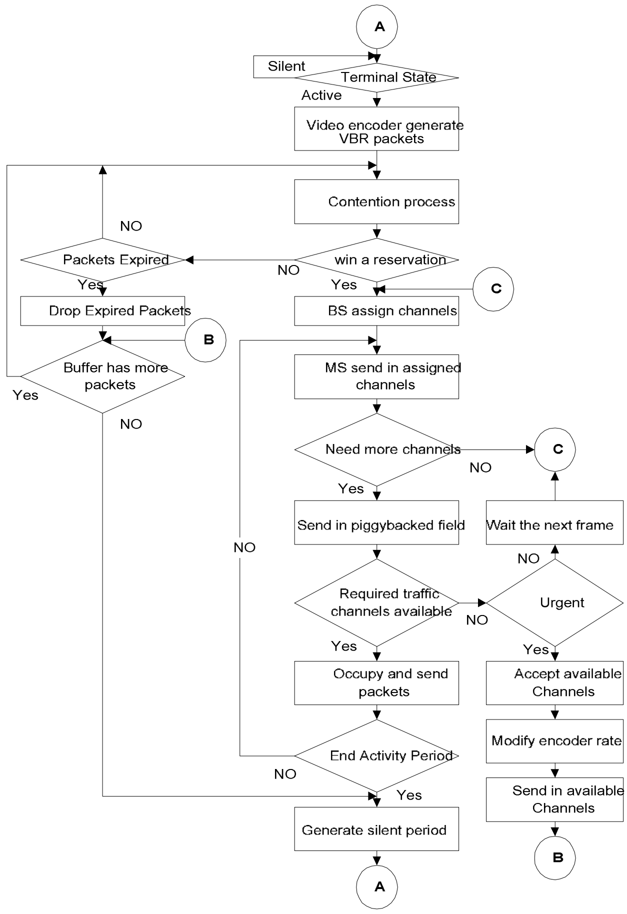

Fig. 5 Flowchart for video reservation process

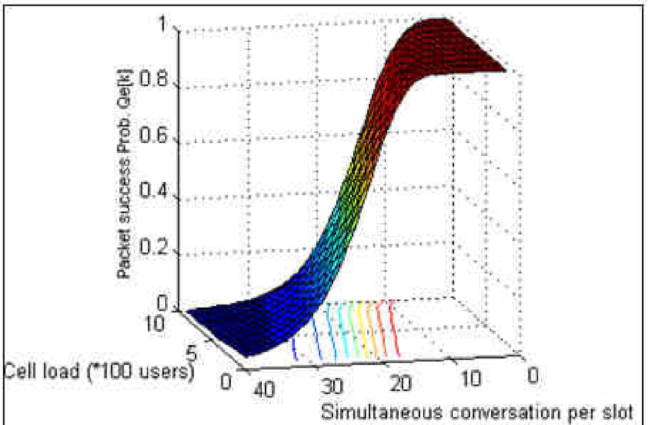

Fig. 6 Packet success probability ver. cell load for reservation subframe at gama=4

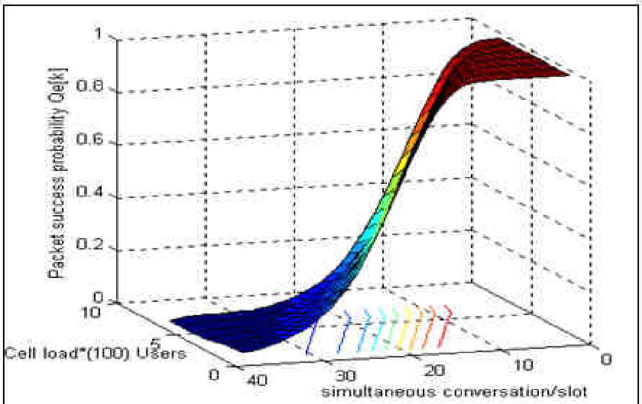

Fig. 7 Packet success probability ver. cell loads for res. subfram at gama=3

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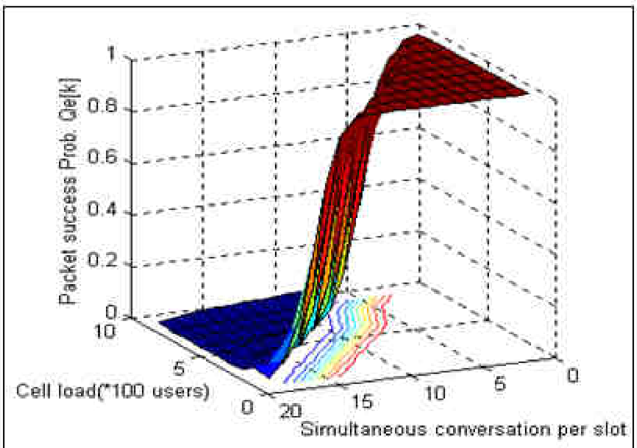

Fig. 8. Packet success probability ver. cell loads for traffic subfram at gama=3

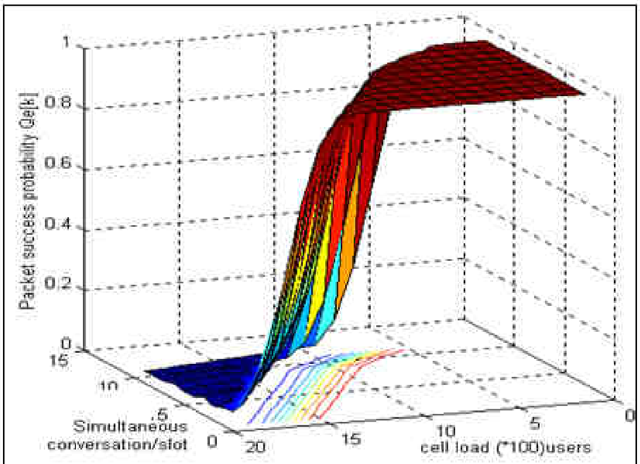

Fig. 9 Packet success probability ver. cell load for traffic subfram at gama=4

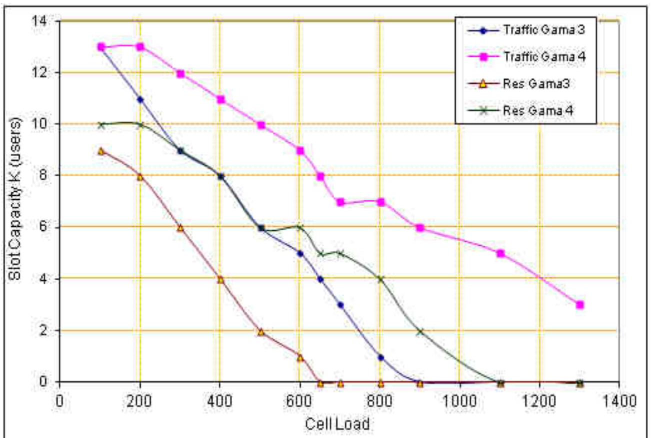

Fig 10 Reservation and traffic Slot capacity versus cell loads in multicell environments (Gama=3, 4).

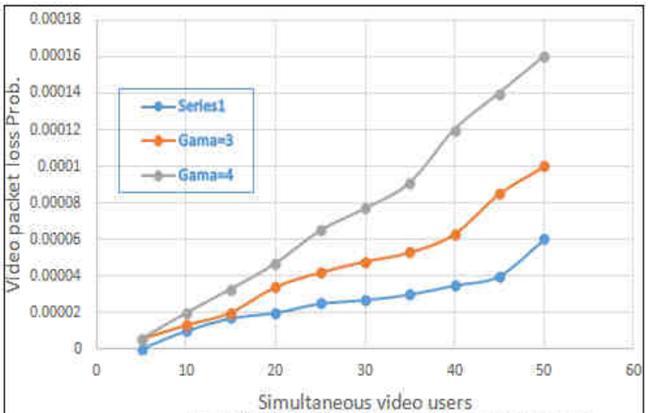

Fig. 11 Probability of Video packet loss in multicell system

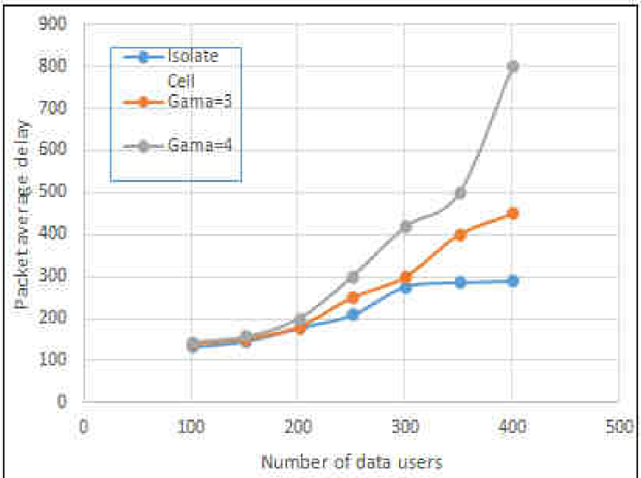

Fig. 12 Data packets average delay in ms for isolated cell and gama=3, 4

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