An Investigation of Satellite Radio Access Technology for Beyond IMT-2000 Systems

Kunseok Kang, Sunheui Ryoo, Byoung Gi Kim, Sooyoung Kim, and Do Seob Ahn

Abstract: **This paper presents an investigation of satellite radio access technology for beyond IMT-2000 systems. Although we could not see any active role of a satellite system in the 3G networks, satellite system will provide strong advantages in future systems for certain applications. Because a satellite link has longer round trip delay than a terrestrial link, we need technologies that would make the satellite component especially efficient. After presenting the satellite radio interface of the 3G system, we suggest several points which need to be considered in the beyond 3G systems. We also suggest a few candidate technologies with various simulation results.**

Index Terms: **B3G, radio access technology, satellite.**

I. INTRODUCTION

Beyond 3G (B3G) systems will include networks with multimode, multi-band, and multimedia high capacity mobile terminals, and many networks will be integrated. In the B3G systems, the major role of satellites will be providing terrestrial fill-in service and efficient multicasting/broadcasting services [1], [2]. As the terrestrial fill-in services, satellite systems provide services and applications similar to those of terrestrial systems outside the terrestrial coverage area as much as possible. In this regard, it is very important to keep commonalities between terrestrial networks. In addition, satellite systems, which have an advantage over terrestrial services for delivery of the same content to users spread over a wide geographic area, will effectively provide multimedia broadcast/multicast service (MBMS) [3]. Based on these technological trends and requirements, we are currently developing efficient radio access technologies for a B3G satellite system, and this paper discusses a part of the results.

As a 3G satellite radio interface, satellite code division multiple access (SAT-CDMA), was proposed by Korea and approved as an ITU-R recommendation in 1999 [4]. The SAT-CDMA was based on wideband CDMA (WCDMA) for a high degree of commonality with the terrestrial component of IMT-2000. As an on-going work, it was updated according to Korean proposals in 2000 and 2001 by incorporating newly developed technologies. The SAT-CDMA has a high degree of commonality with the terrestrial radio specification, IMT-2000 direct spread (DS), but it also has a number of different features. These features, which are necessary to reflect the satellite-specific characteristics, such as long round trip delay (RTD), were implemented in the form of downlink synchronization, uplink packet access, and closed-loop power control [5].

The SAT-CDMA was devised to provide mobile satellite services with a maximum data rate of up to 2 Mbit/s, using a satellite system in low earth orbits (LEO). However, in the B3G system, we are looking for a satellite system in the geostationary earth orbit (GEO) due to many problems discovered in LEO systems. Therefore, there are two main points we should consider in the satellite B3G radio interface. Firstly, we should reinvestigate technologies in the SAT-CDMA because we should deal with a longer RTD by the orbit change from LEO to GEO. Secondly, we should investigate the new technologies developed for the terrestrial B3G system, such as multi-carrier techniques, adaptive coding and modulation (AMC), and etc. In this paper, we analyze these in more detail.

We firstly summarize the main characteristics and features of the satellite radio interface for the 3G system; the SAT-CDMA in Section II. Based on the presentation of the SAT-CDMA, we analyze the satellite radio access technologies required for the B3G system in Section III. Section IV is devoted to describing a few technologies we are currently developing for the B3G system with several intermediate simulation results. In the simulations, we consider a satellite system with a transparent transponder (without on-board processing) in GEO, otherwise specified. Finally, we draw the conclusions in Section V.

II. SAT-CDMA RADIO INTERFACE

The SAT-CDMA was originally devised to provide mobile satellite services with a maximum data rate of 144 kbit/s, using a satellite constellation of 48 satellites in LEO at an altitude of about 1,600 km. Soon after the SAT-CDMA had been modified so that it can be used in various LEO systems with altitudes ranging from 700 km to 1,700 km, and to provide a service rate of up to 2 Mbit/s if the link condition is good and a powerful terminal with a large antenna gain is used. Because the SAT-CDMA considered the satellite system in LEO, it was intended to compensate not only long RTD but also large Doppler shift. For example downlink synchronization channel was designed to compensate the large Doppler shift of LEO system, but this would not be necessary in a GEO system.

The SAT-CDMA defined physical channels similar to those of the terrestrial interface as shown in Table 1. The physical channels with different structures from those of the terrestrial system and the new channels defined in the SAT-CDMA are denoted by * and $^+$, respectively. The difference in physical channels stems from satellite link characteristics distinct from the terrestrial link. In this section, we summarize the main features of the SAT-CDMA which were mainly developed to compensate the long RTD of the satellite system compared to the terrestrial

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Table 1. Physical channels in IMT-2000 DS and SAT-CDMA.

	IMT-2000 DS	SAT-CDMA
Downlink common	SCH	SCH*
	CPICH	CPICH
	P-CCPCH	P-CCPCH
	S-CCPCH	S-CCPCH
	PDSCH	PDSCH
	PICH	PICH
	AICH	AICH*
	AP-AICH	AP/CD/CA-ICH*
	CD/CA-ICH	CSICH
	CSICH	CPCH-CCPCH+
Downlink dedicated	DPCCH	DPCCH*
	DPDCH	DPDCH
Uplink common	PRACH	PRACH*
	PCPCH	PCPCH*
Uplink dedicated	DPCCH	DPCCH*
	DPDCH	DPDCH

Table 2. AICH parameters in the SAT-CDMA.

AICH parameter		Location of Node-B	
		Satellite	LES
$\tau_{p\text{-}p,min}$ (preamble to preamble distance)	chips	230,400	307,200
	access frames	3	4
	ms	60	80
$\tau_{p\text{-}a}$ (preamble to AI distance)	chips	153,600	230,400
	access frames	2	3
	ms	40	60

system [5].

A. Uplink Random Access

One of the main IMT-2000 services is a packet service. In a radio interface, though both dedicated channels and common channels can be used to carry packet data, the common channel shared by users is efficient for bursty transmission. Like the terrestrial interface, the SAT-CDMA defined two types of physical channels to support the bursty transmission in an uplink: A physical random access channel (PRACH) and a physical common packet channel (PCPCH). The PRACH is used to transmit a short packet over one or two frames without the establishment of a prior radio link. The PCPCH is used to transmit a relatively longer packet over a few tens of frames at most. Although the notation and purpose of these channels are the same in both satellite and terrestrial interfaces, we designed a different operation and procedure for the SAT-CDMA in order to incorporate a longer RTD into the satellite link.

In the random access of the terrestrial interface, a user terminal transmits a preamble and receives a detection indication from a radio access network (RAN) before transmitting the data message. The access scheme using a transmission-after-detection-indication causes a severe delay in the satellite link because of the long RTD. In the SAT-CDMA, the user terminal successively transmits the message along with the preamble then waits for a detection indication of successful reception. The physical layer of a satellite-RAN (S-RAN) immediately transmits the indication without latency for signaling and processing in higher layers. This detection-indication-after-transmission scheme can reduce the access delay in comparison with the transmission-after-detection-indication scheme. Because of fast acknowledgement, it also has a shorter retransmission delay than the conventional random access scheme. In the conventional scheme, the response message is not a detection acknowledgement of the RAN physical layer but a higher-layer acknowledgement. The higher-layer acknowledgement cannot be transmitted by the S-RAN within the signaling and processing delay in the higher layers, which depends on the content of the random access message. In considering that, the timing relation between PRACH and acquisition indicator channel (AICH) can be described by the parameter of preamble-to-AI distance in the SAT-CDMA. The parameter value is determined by the RTD in each beam. In the SAT-CDMA, the parameter was set as follows

$$(n-1) \times L_{AF} < RTD_{max} + 2 \times \tau_{off,max} + T_{PS} < n \times L_{AF}, \tag{1}$$

where n is an integer, L_{AF}, RTD_{max}, $\tau_{off,max}$, and T_{PS} are the access frame length, maximum RTD in a beam, maximum transmission offset and processing time required for preamble detection, respectively. The RTD depends on the beam position and the location of the Node-B functionalities. The primary common control physical channel (P-CCPCH) of each beam broadcast AICH timing parameters so that users belonging to the beam are notified of the PRACH/AICH timing relationship. In the SAT-CDMA, this AICH parameter has two different values depending on the location of Node-B functionalities as shown in Table 2. A more detailed description on these can be found in [5].

B. Uplink Packet Access

A modified uplink packet access scheme was included in the SAT-CDMA so that the PCPCH can be efficiently used for a satellite link with a relatively longer RTD. The main elements in the SAT-CDMA that are different from the terrestrial counterpart can be summarized as follows: One-step access/channel assignment, the use of a downlink common control channel for PCPCH transmission and power control, and a power control speed of 100 Hz.

In the terrestrial interface, a user terminal transmits an access preamble (AP) as it does the PRACH preamble. After the user terminal receives a positive acknowledgement from the RAN, it transmits a collision detection preamble (CDP). The user terminal cannot acquire permission to access a PCPCH until it receives a positive acknowledgement from the RAN corresponding to the last CDP. This two-step access is inappropriate for satellite systems because it requires at least two times the RTD.

In the SAT-CDMA, a user transmits a combined preamble to obtain an access grant. The combined preamble consists of an AP and a CDP, both of which have the same structures as those of the terrestrial counterparts. The S-RAN responds to the preamble, transmitting two consecutive acknowledgements. The user terminal, thus, can obtain transmission permission and channel assignment by a one-step access mechanism.

Therefore, the power control period was designed to be equal to a radio frame length. In order to control the transmission and power on the uplink PCPCH, the SAT-CDMA defines a downlink CPCH common control physical channel (CPCH-CCPCH). Up to 15 CPCHs in a CPCH set are associated with the common control channel. Unlike in the terrestrial interface, the transmission power of the downlink channel is not controlled by each PCPCH. Additionally, by using a common control channel instead of several pairs of dedicated control channels, the number of available channelization codes for the downlink can be reduced.

C. *Closed Loop Power Control*

Because of a significant difference of the RTD, we have serious performance degradation of the closed loop power control (CLPC) if the power control used for the terrestrial interface is employed as it is. In order to reduce the power control error a delay compensation mechanism was selected in the SAT-CDMA [5]. For the case of the uplink CLPC, the user equipment (UE) calculates the actual amount of the transmission power control by using the two most recently received power control commands, which are aimed to change the loop dynamics and shorten the latency in updating transmission power. For the case of the downlink CLPC, the UE may employ a prediction algorithm that estimates the future signal-to-interference ratio (SIR) value after a RTD by observing the SIR of the downlink common pilot channel (CPICH). The power control command is generated on the basis of the predicted SIR value. We will discuss this CLPC algorithm in more detail for the application to a GEO system in Section IV.

III. SATELLITE RADIO ACCESS TECHNOLOGY FOR B3G

A. *Reinvestigation of Satellite Technologies in the SAT-CDMA*

In this section, we reinvestigate the satellite specified technologies in the SAT-CDMA in order to tailor the target satellite system in GEO. If we change the satellite orbit to GEO at an altitude of about 35,800 km from LEO, we will have much longer RTD. Because the satellite specified technologies in the SAT-CDMA were mainly developed to compensate long RTD, it may show stronger advantages in GEO systems. However, the technologies developed to compensate the Doppler shift such as the downlink synchronization code would not be necessary.

Because the CLPC scheme in the SAT-CDMA employs a delay compensation algorithm, it would produce a good performance in the GEO system. In the next section, we will demonstrate a few simulation results of the CLPC algorithm in the GEO system.

For the random access schemes, we need modifications by considering the RTD of the GEO system. We firstly consider the PRACH/AICH timing relation and re-estimate the AICH_Transmission_Timing in the GEO system. Fig. 1 shows RTD difference, Δ_{RTD} in a satellite beam according to the satellite height and spot beam size. We have larger Δ_{RTD} with higher altitude and larger beam size. Fig. 1 indicates that Δ for satellite height of even 36,000 km and beam size of 2,000 km is smaller than 20 ms. This implies that we do not have to change the length of the access frame in AICH and PRACH preamble in the GEO system.

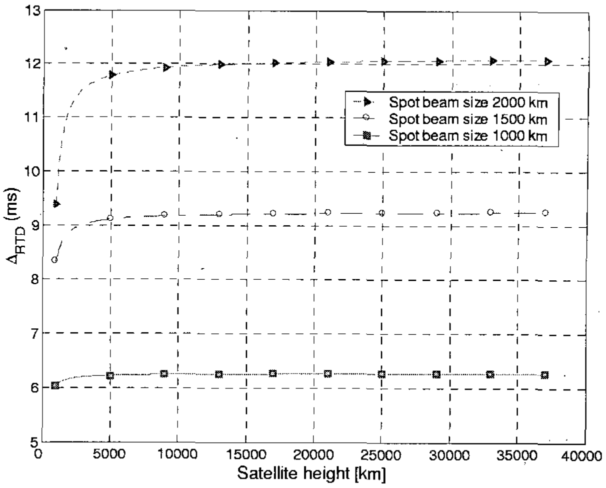


Fig. 1. Difference between the maximum and minimum RTD, Δ_{RTD} in the satellite spot beam (minimum elevation angle of 16°).

Table 3. AICH parameters for the GEO systmem.

AICH parameter		Location of Node-B	
		Satellite	LES
$\tau_{p-p,min}$ (preamble to preamble distance)	chips	1,152,000	2,150,400
	access frames	15	28
	ms	300	560
τ_{p-a} (preamble to AI distance)	chips	1,075,200	2,073,600
	access frames	14	27
	ms	280	540

Secondly, we consider PRACH/AICH timing relation, and have to change the AICH timing parameters in Table 3 in order to deal with long RTD. The RTD of a GEO system is about 250 ms and 500 ms if the Node-B functionalities are in the satellite and in the land earth station (LES), respectively. By using this, we re-estimate the AICH parameters as shown in Table 3.

B. *Investigation of New Technologies*

In the SAT-CDMA, we did not consider the spatial diversity gain because we assume a prevailed line of sight (LOS) condition. However, if we combine the spatial diversity with time diversity such as space time transmit diversity (STTD), this may improve the performance. One of our study results showed that the STTD scheme showed appreciable performance gain in a mobile satellite channel [6], and we will demonstrate a part of the simulation results in the next section.

The AMC and hybrid ARQ (H-ARQ) scheme is one of the essential parts that should be included in the new radio interface. We are investigating on adaptive coding with H-ARQ scheme with rate compatible block turbo codes [7], and we will describe a candidate scheme and its simulation results in the next section.

For the efficient use of frequency resources and high-speed data services, multi-carrier based technologies such as orthogonal frequency division multiplexing (OFDM) and multi carrier-CDMA (MC-CDMA) are considered as the most promising technologies to provide future mobile services in the B3G or 4G systems [8]–[10]. In order to keep commonalities with the terrestrial system in the B3G or any future systems, multi-carrier transmission techniques for a satellite system are essential technologies to be studied. As a reflection on this requirement, an MC-CDMA satellite system with a multiuser detector was proposed [11]. In addition, our previous study investigated an adaptive MC-CDMA technique for mobile satellite systems [12], [13], and this would be a strong candidate scheme in the new satellite radio interface.

For MBMS, medium access control (MAC) architecture of the SAT-CDMA should be modified. In case of the 3rd generation partnership project (3GPP), the new logical channels of MBMS point-to-multipoint control channel (MCCH) and MBMS point-to-multipoint traffic channel (MTCH) are defined for point-to-multipoint transmission, and MAC architecture is modified to use MCCH and MTCH [3]. The block of 'add MBMS-ID' is added and a pre-existing 'Scheduling/Priority Handling' block should be modified to support MBMS. In UE side MAC architecture, 'read MBMS-ID' block is added for MBMS.

IV. A FEW CONDIDATES FOR SATELLITE RADIO ACCESS TECHNOLOGY FOR B3G

A. Power Control

The RTD of a GEO system results in significant performance degradation of the CLPC if the 3GPP standard is employed as it is [13]. There are two main problems that degrade the CLPC under such a long RTD. The first one is the instability in the internal loop dynamics due to the fact that the power control step size specified in 3GPP is too large to keep the loop stable under such a long loop delay. In other words, the measurements at UE do not reflect the results of the most recent power updates at the S-RAN. The second one is the possibility of the large amount of SIR change during the loop delay thus resulting in large power control errors.

As one of the effective solutions to the first problem, Gunnarsson proposed a delay compensation power control scheme [14], [15], and this was reflected in the S-UMTS standard [16]. Although this effectively cancels the internal RTD in the power control loop, we still have the second problem.

In order to solve the second problem, we proposed a prediction algorithm that estimates the future SIR value after a RTD [5]. Now, we will explain it in more detail by focusing the downlink CLPC scheme. Fig. 2 shows the block diagram of the proposed downlink CLPC. We apply it to a GEO system and demonstrate the delay compensation performance. Power control adjusts the S-RAN transmit power in order to keep the received downlink power SIR at a given SIR target, SIR_{target}. The UE estimates the SIR of the received downlink dedicated physical control channel (DPCCH) and the SIR variation of the received CPICH since the CPICH channel is not power controlled. Based on this SIR estimation, the UE generates two-bit transmit power control (TPC) commands and transmits them every 10 ms (per frame) [4].

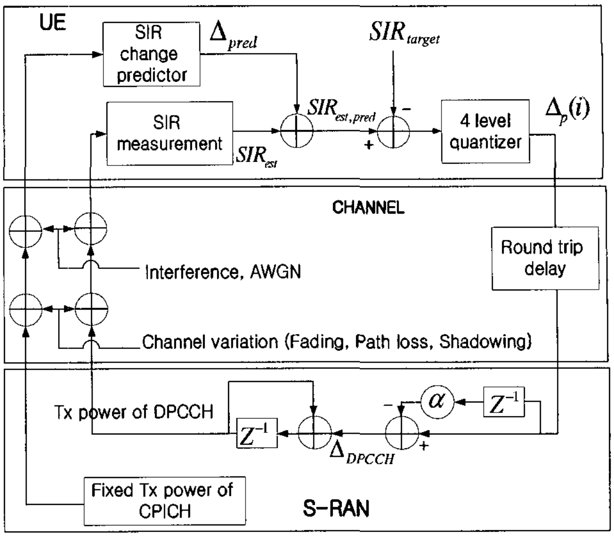


Fig. 2. The block diagram of the downlink CLPC scheme.

The TPC commands are generated by the following rule. At first, let us define the power control error of $\Delta_{\varepsilon,c} = SIR_{est} - SIR_{target} + \Delta_{loop\ delay}$, where $\Delta_{loop\ delay}$ and SIR_{est} denote the prediction for the amount of SIR increment/decrement of the received downlink CPICH and the estimated SIR of the received downlink DPCCH during the next time interval equal to the loop delay, respectively. Therefore, $\Delta_{loop\ delay}$ is added to SIR_{est} to result in the predicted SIR value of $SIR_{est,pred}$. In other words, we employed a simple algorithm for the calculation of $\Delta_{loop\ delay}$ as follow

$$\Delta_{loop\ delay} = n \times \Delta_{pred}, \tag{2}$$

where $n \times \Delta_{pred}$ is the increment (or decrement) of the estimated SIR of CPICH in dB during the last frame and n is the nearest integer to (loop delay)/(frame length).

A four-level quantized power control step Δ_p is generated according to the region of Δ:

$$\begin{array}{ll} \text{if } |\Delta_{\varepsilon,c}| < \varepsilon_T \text{ and } \Delta_{\varepsilon,c} < 0, \Delta_p(i) = & \Delta_S \\ \text{if } |\Delta_{\varepsilon,c}| < \varepsilon_T \text{ and } \Delta_{\varepsilon,c} > 0, \Delta_p(i) = & -\Delta_S \\ \text{if } |\Delta_{\varepsilon,c}| > \varepsilon_T \text{ and } \Delta_{\varepsilon,c} < 0, \Delta_p(i) = & \Delta_L \\ \text{if } |\Delta_{\varepsilon,c}| > \varepsilon_T \text{ and } \Delta_{\varepsilon,c} > 0, \Delta_p(i) = & -\Delta_L, \end{array} \tag{3}$$

where Δ_S, Δ_L, and ε_T are a small power control step, a large power control step, and the error threshold, respectively.

Because of the RTD in the GEO system, the S-RAN can reflect $\Delta_p(i)$ at its transmission power after about 250 ms during which time there may be a considerable change in the SIR. We employ a simple preprocessing for $\Delta_p(i)$ before it is reflected at the transmission power in order to compensate for the RTD. The S-RAN adjusts the transmit power of the downlink DPCCH with an amount of DDPCCH using the two most recently received power control steps, $\Delta_p(i)$ and $\Delta_p(i-1)$, and this can

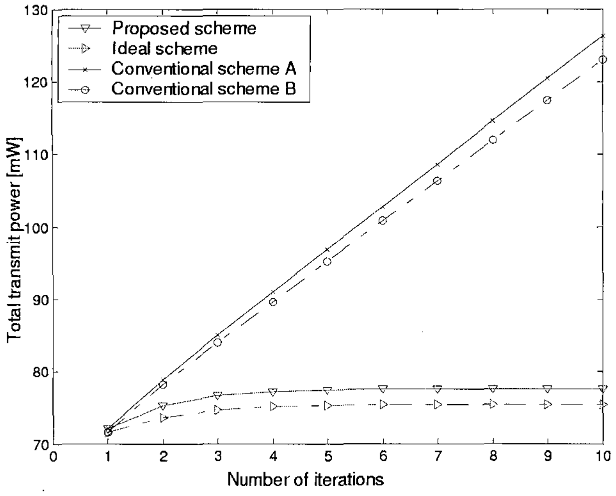


Fig. 3. Total power transmitted from 250 users.

be modeled as a simple finite impulse response filter (FIR) as follows

$$\Delta_{DPCCH} = \Delta_p(i) - \alpha\Delta_p(i-1). \tag{4}$$

We can rewrite the above equation as follows

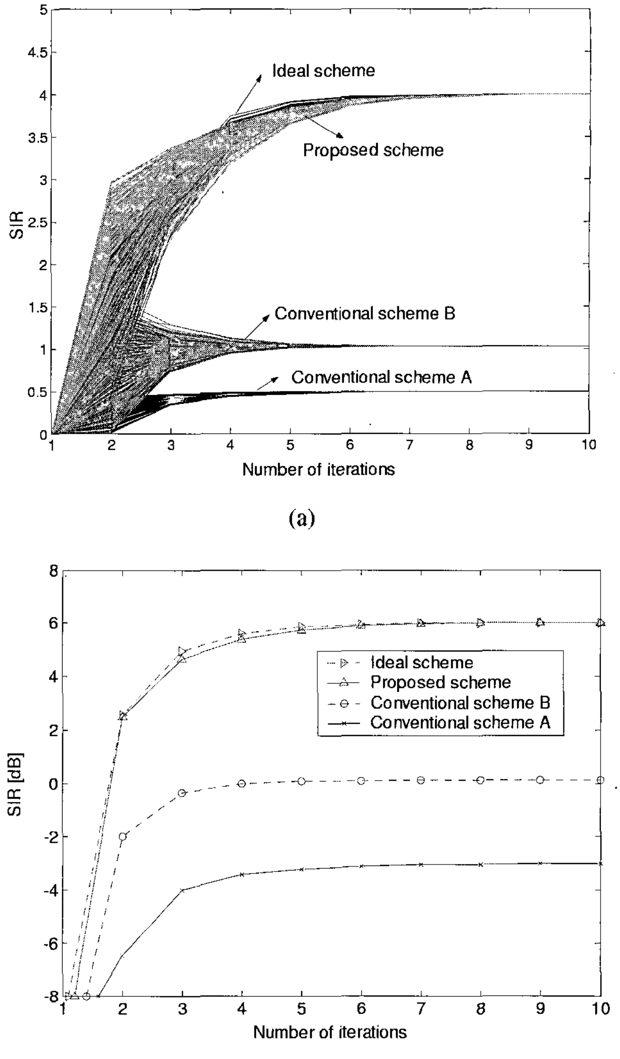
$$\Delta_{DPCCH} = (1-\alpha)\Delta_p(i) - \alpha(\Delta_p(i) - \Delta_p(i-1)), \tag{5}$$

which means that Δ_{DPCCH} is determined not only by $\Delta_p(i)$ but also by the difference between $\Delta_p(i)$ and $\Delta_p(i-1)$ with weighting factors of $(1-\alpha)$ and α, respectively. As α increases, Δ_{DPCCH} becomes more dependent upon the term $\Delta_p(i) - \Delta_p(i-1)$, which corresponds to an estimate for the amount of the recent channel variation.

In Figs. 3 and 4, we present the simulation results of the proposed CLPC scheme over GEO-based environments, and compared the performance of the various conventional CLPC algorithms [13], [16]. As the conventional schemes, we used the terrestrial CLPC scheme in the WCDMA system [13] and Gunnarsson's scheme in [16], and they are denoted as conventional schemes A and B in the figures.

In our simulations, we consider a satellite system with a single beam and ignore the inter-spot interference. We assume that the UE are uniformly distributed on a disk of radius of 500 kilometers around the center of the beam. The path loss exponent of α is taken to be 2. At the beginning of the iterations, the power vector is initialized to zero and the filter coefficients are initialized to the orthogonal variable spreading factor (OVSF) of the users. For the simulations we chose a common SIR of 4 (= 6 dB). We select the processing gain (PG) of 256 and PG chips were assigned to each user. We assumed the number of users is 250.

Fig. 3 shows total power consumed at the transmitters of 250 users. We can see that users with the proposed CLPC scheme consume less power, and it shows very close performance to the ideal power control scheme. The lower power consumption will directly lead to the capacity increase. The superior power control performance is due to more accurate estimation of SIR. This is illustrated in Fig. 4, where we can see the convergence performances of 250 users to the target SIR in the various CLPC schemes. As we can see in Fig. 4(a) where the convergence performances of all 250 users are shown, powers of all users with the proposed CLPC scheme converge to the target SIR of 4 (= 6 dB). For simple comparison, we redraw the convergence performance by averaging those of 250 users and depict in dB scale in Fig. 4(b). It clearly shows that the conventional systems leave a large estimation error of more than 6 dB.



(a)

(b)

Fig. 4. Convergence rate comparison of various power control schemes: (a) 250 indivisual users, (b) average of 250 users.

B. Space Time Transmit Diversity

The space-time codes are considered one of the most promising techniques to meet service quality and speed required in the next generation wireless communications systems [17]. Following Alamouti's work, many further researches have been devoted to the terrestrial systems, where we can get high diversity gain from a large number of multi-paths due to its small coherence bandwidth. In mobile satellite systems, it is very difficult to get such an advantage due to its inherent large coherence bandwidth. For this reason, authors in [18] suggested the space-time

Table 4. The simulation parameters for STTD in the satellite system.

Downlink	Parameter	Values
Tx.	Information bit rate	30 kbps
	Spreading factor	256
	Over-samples	5 per chip
	Chip rate	3.84 Mcps
	Number of antennas	2
	Carrier frequency	2 GHz
Rx.	Number of antennas	1 or 2
	Searcher	Variable
	Power control	Perfect
	Detection algorithm	Maximum likelihood (ML)
	Bit synchronous	Perfect
	Channel estimation	Slot by slot basis, $\sigma_E^2 = 0.1$ dB

minimum mean square error (MMSE) reception with two satellites.

In most of the previous works on STTD scheme, perfect channel estimation was assumed [17], [18]. It was also assumed that channel gain was always a constant which was defined as quasi-static Rayleigh fading (QSRF) during the transmitter transmits 2 symbols. However, in practice we can neither get ideal channel estimation in downlink nor QSRF. We simulated the performance of the STTD scheme for satellite WCDMA systems with two antennas in the transmitter and 1 or 2 antennas in the receiver. The essential parameters used in the simulation are summarized in Table 4. The spreading factor of 256 in Table 4 is applicable to the data transmission with low rate, CPICH and P-CCPCH in downlink of satellite WCDMA system.

Figs. 5 and 6 show the performance of the satellite WCDMA system using space-time codes with and without channel estimation, respectively. In the channel estimation, we assume that the estimation is performed on a slot-by-slot basis with a power control error, σ_E^2 of 0.1 dB. For the comparison of a terrestrial system with the same scheme, we plot the performance of the terrestrial WCDMA system using the same STTD scheme in Fig. 7. In the terrestrial STTD scheme, we assume perfect channel estimation. In the simulation results we used a tapped delay line multi-path fading models [6], [19]. For the terrestrial channel, we used Rayleigh fading at the multi-paths, and for the satellite channel we used Rician fading with various Rician factors of K at the first path with line of sight condition.

The performance of terrestrial STTD scheme is highly dependent on the number of antennas. On the other hand, Figs. 5 and 6 show that the performance of satellite STTD scheme is highly dependent on K. This may imply that the performance of satellite STTD scheme is more dependent on space diversity than time diversity. In other words, satellite STTD scheme provides appreciable performance gain although we cannot get much advantage from time diversity due to small delay spread. The simulation results in Figs. 6 and 7 show that the diversity gain from the proposed STTD scheme in mobile satellite systems exceeds that in the terrestrial system with Rician factor K of 20 dB (open or rural area) with a reasonable amount of SNR value (≥ 4 dB) owing to space diversity gain even without channel estimation. Fig. 6 shows that channel estimation in low SNR range (< 6 dB) deteriorate the performance of the satellite STTD scheme rather than boosting it.

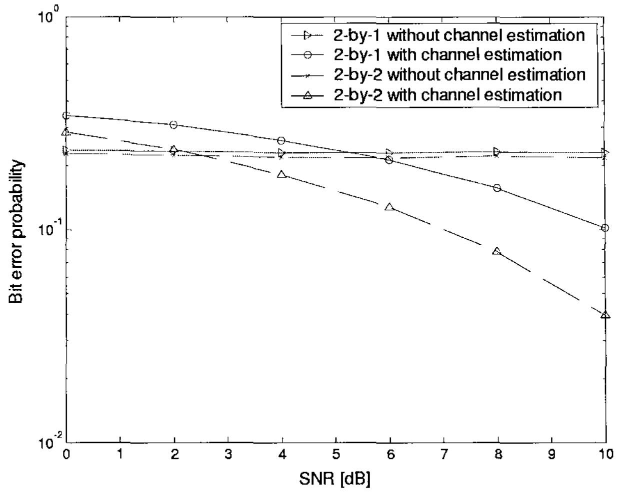


Fig. 5. Performance of satellite WCDMA using STTD at Rician factor $K = 0$ dB.

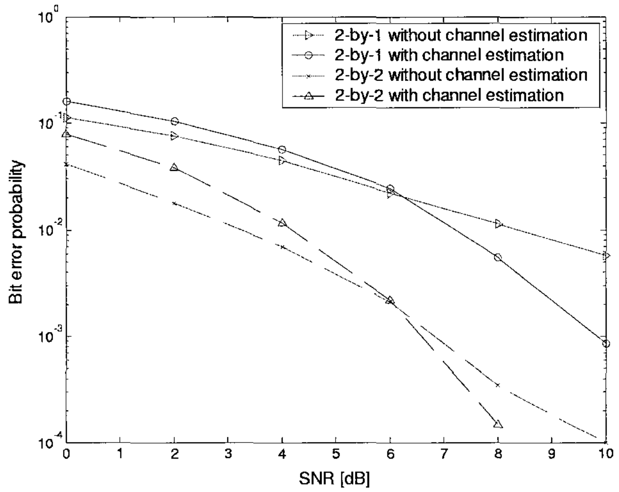


Fig. 6. Performance of satellite WCDMA using STTD at Rician factor $K = 20$ dB.

C. Hybrid ARQ and Adaptive Modulation and Coding

It is evident that a mobile satellite communication system should be equipped with an efficient H-ARQ and AMC scheme in order to contribute to a future integrated mobile communication system. In a satellite channel, the primary impairment on performance is shadowing on a longer time scale due to blockage rather than multipath fading. In a deep shadowing condition, the average SNR is too low for reliable detection even with powerful forward error correction (FEC). As one of the promising solutions to this, the adaptive hybrid ARQ/FEC schemes to architect a flexible link/data link layer were proposed for mobile satellite systems [20], [21]. Most of the previous proposed hybrid ARQ and/or adaptive FEC schemes were based on rate compatible (RC) convolutional codes or conventional convolu-

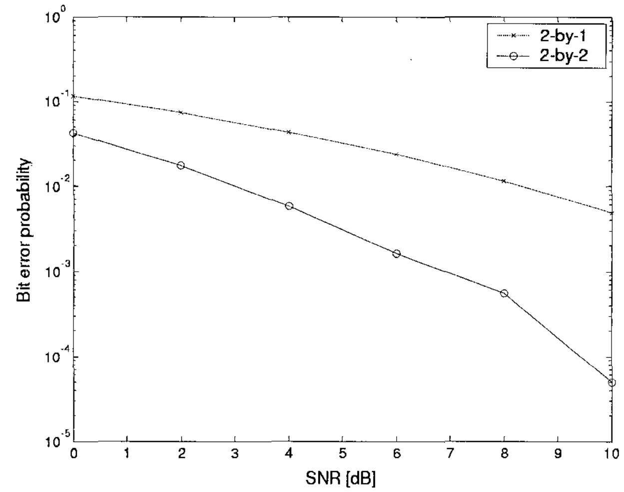


Fig. 7. Performance of terrestrial WCDMA using STTD.

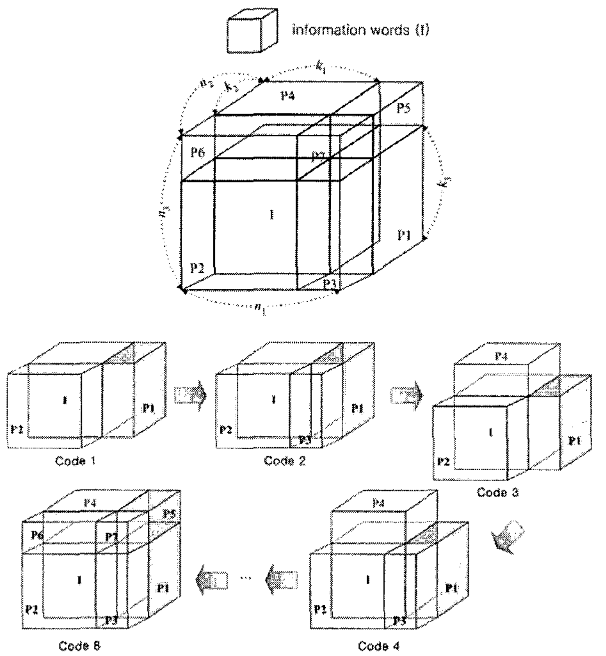


Fig. 8. Example of RC block turbo code using a 3D product code.

tional turbo codes.

In this paper, we propose a rate adapted H-ARQ scheme using RC block turbo codes [7]. The high dimensional block turbo codes enable us to produce an abundance of code rates and coding gains. Furthermore, this code can be encoded and decoded in parallel due to the independence of the consisting codes. Fig. 8 shows an example of an RC block turbo code using a 3D product code and its application to H-ARQ schemes.. All patterns of RC block turbo code in Fig. 8 are based on the 3D block turbo codes. In the proposed scheme, we first apply the adaptive coding scheme with the RC code based upon the given channel quality information (CQI). Therefore, we send the most appropriate code to the CQI at the first transmission instead of sending the highest rate code as in the conventional H-ARQ scheme.

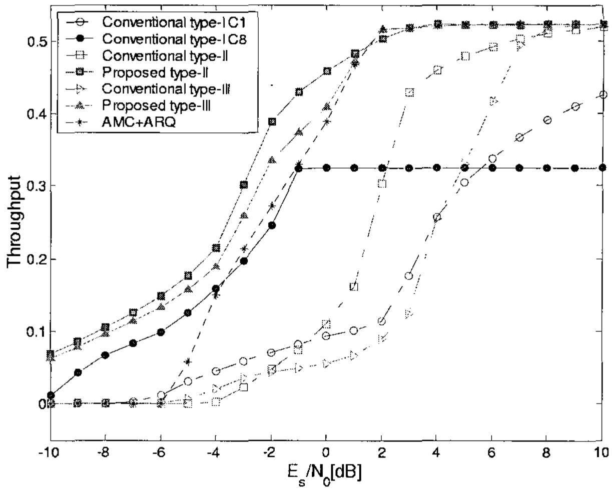


Fig. 9. Throughput performance of the H-ARQ and AMC.

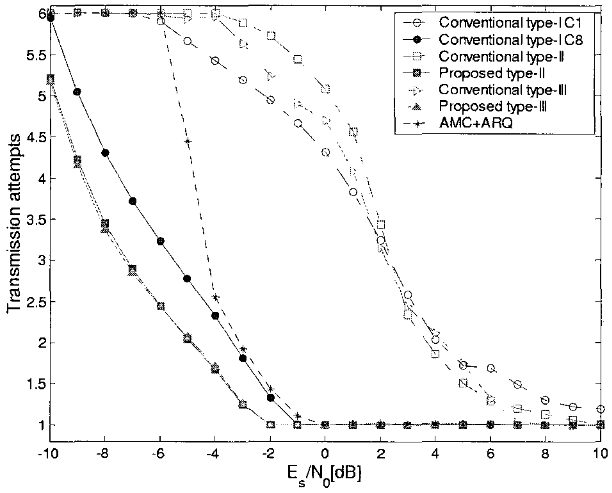


Fig. 10. Delay performance of the H-ARQ and AMC.

We estimated the performance of the adaptive H-ARQ systems compared with various types of the conventional H-ARQ and AMC schemes on a mobile satellite communication channel. As a RC product code, we use 3D block turbo codes using the (16, 11) extended BCH code. The RC codes made by various combinations of the sub-blocks of the 3D block turbo codes have various code rates and error correction capabilities. A selective-repeat automatic retransmission query was applied to reduce retransmission delay.

Figs. 9 and 10 show the throughput and delay performance of various type H-ARQ schemes, respectively. We define the throughput as the ratio of the number of the correctly decoded information bits to the number of bits transmitted in total. We limited the maximum number of transmissions to six times with which we can make a full 3D product code in this simulation.

In type-I scheme we use two fixed codes at every transmission. In other words, whenever the transmission fails, we always transmit the same code. In our simulation of type-I H-ARQ schemes, we used the lowest rate code (C8) and the highest rate code (C1) in the RC code group as in Fig. 8. Based on our throughput performance simulation in Fig. 9, type-I H-ARQ schemes with C8 outperforms that with C1 in low SNR range. However, as the SNR increases, the throughput performance of type-I scheme with C8 is limited to the code rate of C8.

If the first transmission fails in type-II schemes, we send only the incremental redundancy block that can make the higher rate RC code at the successive retransmissions. On the other hand, in type-III schemes, we send full RC code blocks at every retransmission in order. The conventional type-II and type-III H-ARQ start to transmit with the highest rate code, so early transmission can be failed in deep fading channel condition.

The adaptive H-ARQ with block turbo codes adjusts the first transmission code adaptively to the channel conditions. The proposed scheme reduces the number of retransmission attempts by about 15% $\sim$ 75% compared to the conventional H-ARQ schemes in E_s/N_0 range less than 6 dB level of channel SNR as shown in Fig. 10. This delay reduction leads to the throughput performance improvement in Fig. 9. In lower SNR region than 0 dB, the H-ARQ schemes with rate adaptation outperforms than the AMC schemes because of Chase combining and incremental redundancy transmissions. The adaptive H-ARQ can increase throughput in severe shadowing conditions and then can extend the operating SNR region. If we use a coding scheme which can provide a large variety of the code selections in the retransmissions, we can obtain larger performance gains.

V. CONCLUSION

In this paper, we present satellite access technologies for future mobile systems. By analyzing the main features of the satellite component of the IMT-2000 systems, we suggested desirable modifications for the application to beyond 3G system. Closed loop power control scheme with delay compensation algorithm was proved to provide a good performance in a GEO satellite system. We also demonstrated simulation results of a few new radio access technologies including adaptive coding with H-ARQ, STTD, indicating these can provide enhanced performance in mobile satellite channels. In addition, not only to increase the performance but also to keep commonalities with terrestrial standards, more advanced transmission technologies including multi-carrier transmission, interference cancellation, and highly efficient modulation and coding should be investigated in more detail.

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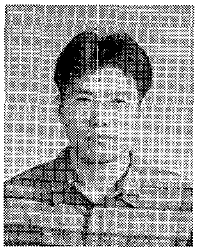

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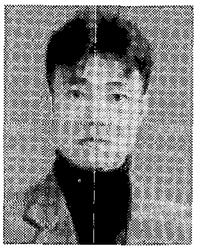

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