An Efficient Power Control Algorithm for Satellite Communications Systems with ATC

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***Abstract*—In this paper, modified power control algorithms are proposed for a satellite mobile communications system with ATC (ancillary terrestrial component). In order to increase system capacity and reduce the transmitting power of the user's equipment, we propose the modified power control scheme consisting of the modified closed-loop and open-loop power control. The modified CLPC (closed-loop power control) algorithm, combining the delay compensation algorithms and pilot diversity, is mainly applied to the ATC link in urban areas because it is more suitable to the short RTD (round-trip delay). In the case of rural areas where ATCs are not deployed or a signal is not received from ATCs, combining monitoring transmitting power equipment and OLPC (open-loop power control) algorithms using an efficient pilot diversity is mainly applied to the link between the user's equipment and the satellite. Two power control algorithms are applied equally to the boundary areas where two kinds of signals are received in order to ensure coverage continuity. The simulation results show that the modified power control scheme has good performance compared to conventional power control schemes in a GEO (geostationary earth orbit) satellite system with ATC.

Index Terms*—*Ancillary Terrestrial Component, modified power control scheme, OLPC, CLPC

I. INTRODUCTION

New standards in the framework of so-called 4G systems will include networks with multi-mode, multi-band, and multimedia high capacity mobile terminals, and many networks will be integrated. Such future systems should be able to fulfill the stringent requirements for QoS (quality of service), mainly in terms of throughput, delay, and error rate. In the 4G systems, the major role of satellites will be to provide terrestrial fill-in service and efficient multicasting/ broadcasting services [1]. However, it is known that it is difficult for a MSS (mobile satellite service) to reliably serve densely populated areas because satellite signals are blocked by high-rise structures and/or do not penetrate into buildings. Under these circumstances, in a groundbreaking application to the FCC (Federal Communication Commission) in 2001, MSV (Mobile Satellite Ventures) LP unveiled a bold new architecture for an MSS with an ATC (Ancillary Terrestrial Component) providing unparalleled coverage and spectral efficiency [2]. The main concept of the hybrid MSS/ATC architecture of the MSV proposal is that terrestrial reuse of at least some of the satellite band service link frequencies can eliminate the above-mentioned problem.

In the power control of conventional land mobile satellite communication systems containing ATC [6], the power control scheme of the user's equipment from the serving ATC is based on a combination of terrestrial open- and/or closed-loop methods, and the power control scheme of the user's equipment from the serving satellite is not described in detail. However, contrary to terrestrial communication systems, open- and closed-loop power control of the land mobile satellite systems has only marginal benefit because of the lengthy round-trip delay between the mobile and satellite/ATC. In order to solve the above problem, this paper added monitoring equipment to use information about the transmitting power that has not yet experienced by the receiver over the satellite/ATC channel [4].

Based on these technological trends and requirements, we are currently developing efficient power control and handover technologies for a hybrid MSS/ATC system; this paper discusses a part of the results. We firstly describe the system model. In Section III, we describe the modified open-loop power control, and Section IV is devoted to describing the modified closed-power control technology. In simulations, we mainly consider a satellite system with a transparent transponder (without on-board processing) in a GEO (geostationary earth orbit). The simulation results and discussions are given in Section V. Finally, we draw the conclusions in Section VI.

II. SYSTEM MODEL

Figure 1 illustrates the MSV's hybrid system architecture. Land mobile satellite systems and methods are widely used in radiotelephone communications. The satellite is configured to transmit wireless communications to a plurality of UE (users' equipment), UE in a satellite footprint composed of one or more satellite spot-beam over one or more MSS forward/ reverse link [3]. The satellite is configured to receive wireless communications from, for example, UE in the satellite spot-beam over MSS return link. An ATC

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network, composed of at least one ACT, which may include an antenna, is configured to receive wireless communications from other UE. ATC networks can enhance cellular satellite radiotelephone system availability, efficiency, and/or economic viability by terrestrially reusing at least some of the frequency bands that are allocated to cellular satellite radiotelephone systems.

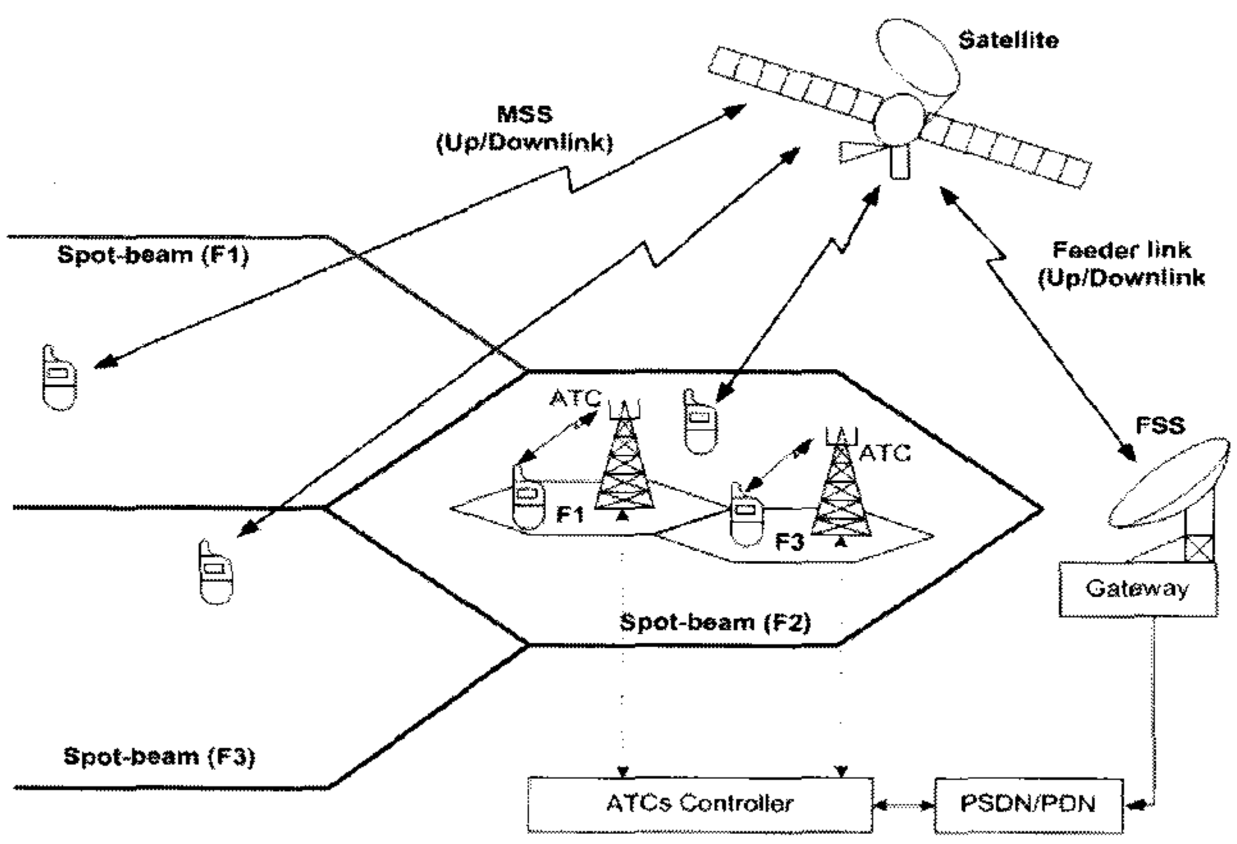

Fig. 1 MSV's hybrid system architecture.

In particular, it is known that it may be difficult for cellular satellite radiotelephone systems to reliably serve densely populated areas, because the satellite signal may be blocked by high-rise structures and/or may not penetrate into buildings. As a result, the satellite spectrum may be underutilized or unutilized in such areas. The terrestrial reuse of at least some of a satellite band's frequencies can reduce or eliminate this potential problem. However, both accurate power control and an efficient handover are vital because all CDMA signals interfere with each other. Lack of accurate power control reduces the capacity for CDMA. Moreover, power control can reduce battery drain and increase possible talk time. The major objective of power control is to alleviate co-channel and cross-channel interference.

III. OPEN-LOOP POWER CONTROL

Conventionally, uplink and downlink power control may be based on a combination of open- and/or closed-loop methods. A modified OLPC and CLPC model is shown in Fig. 2. In the open-loop power control, the UE estimates a transmitting power level, which may maintain a desired signal quality and/or strength at a BTS (base transceiver system) or base station, by monitoring its own received quality. This technique is crucial to the system performance due to its role in preventing near-far effect and mitigating fading. The open-loop power control adjusts the transmitted signal power level according to the received forward link signal strength. Hence, it mainly compensates for path loss and shadowing, while the CLPC is designed to compensate for the small-scale fading caused by the multipath in the transmission on the reverse link, which is different from that on the forward link, due to the frequency separation of the links.

As mentioned in Section II, in order to improve the accuracy of the estimation of SIR, we proposed a method to estimate the interference power, which will be shown in Fig. 3.

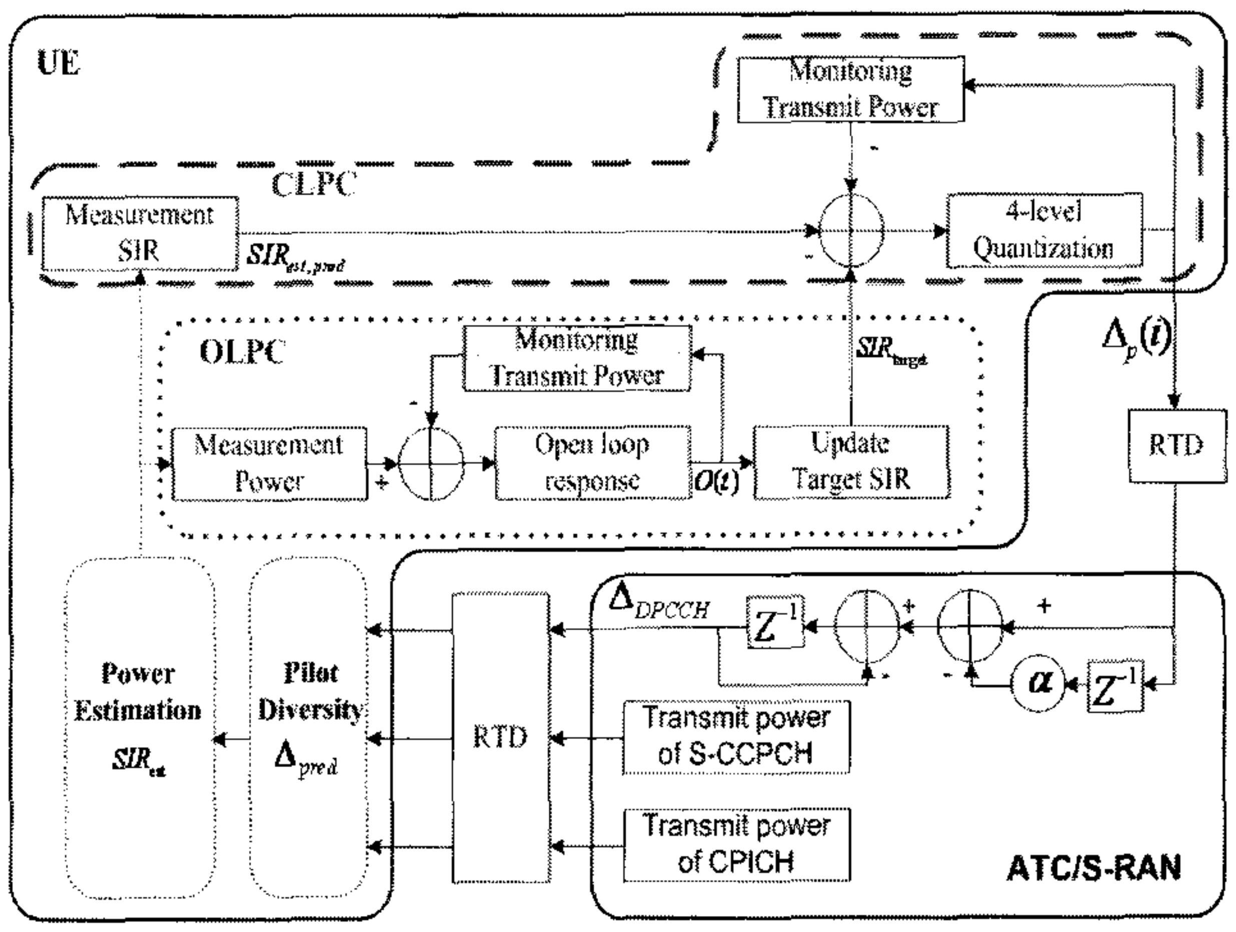

Fig. 2 Modified OLPC and CLPC model.

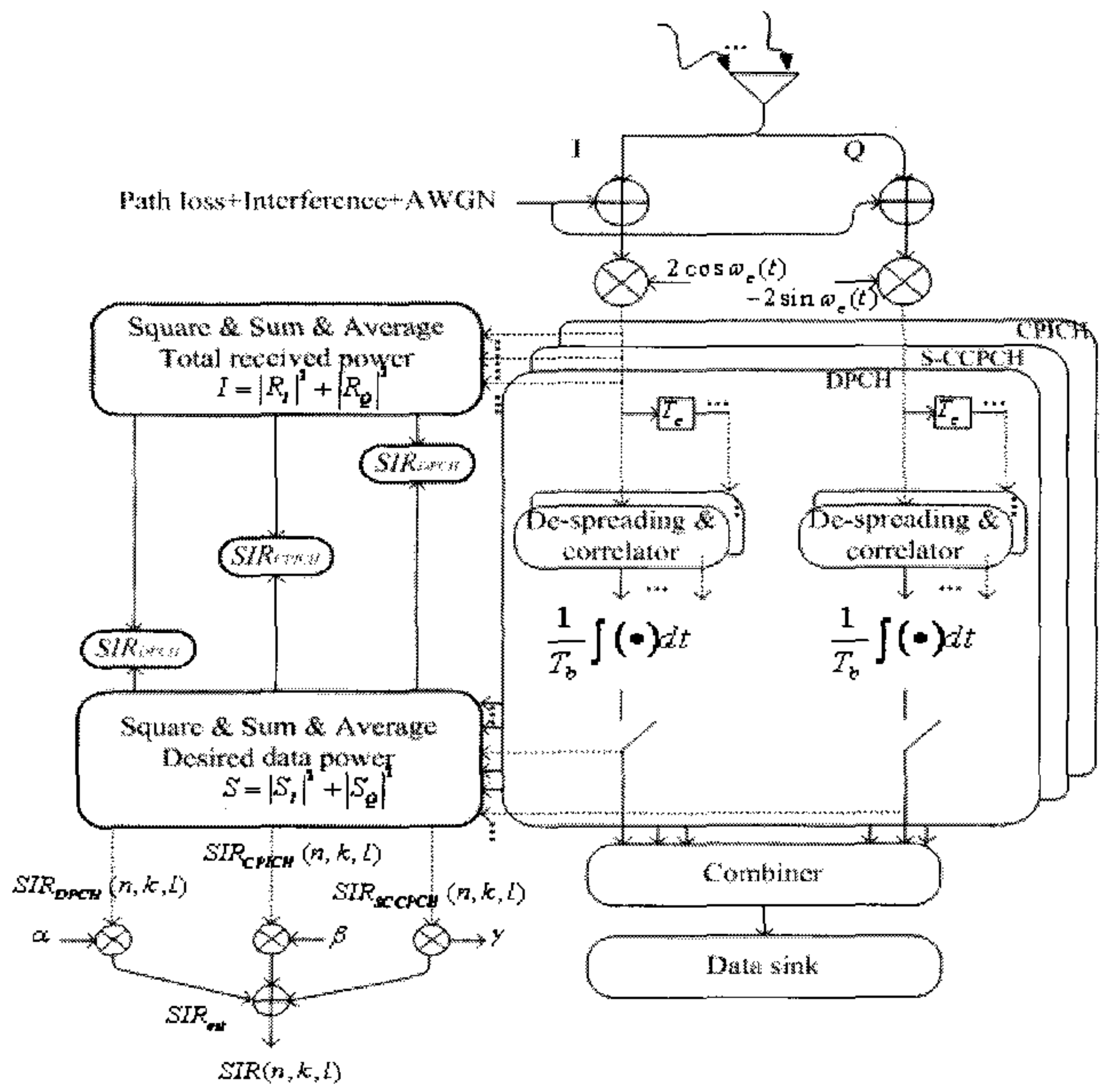

Fig. 3 Block diagram of power estimation using pilot diversity.

n, k, l, T_b, and T_c denote n-th slot, k-th symbol, l-th resoluble multi-path, bit duration, and chip duration, respectively. In addition $SIR_{DPCH}(n,k,l)$, $SIR_{CPICH}(n,k,l)$, and $SIR_{SCCPCH}(n,k,l)$ stand for estimates of DPCH, CPICH, and SCCPCH, respectively. SIR is an important power control system parameter that has a propound effect on system capacity as the wanted signal and the interference have the same bandwidth at the output of the digital matched filter, SIR. Since the interference noise is Gaussian distributed, the variance of the interference can be found from the sum of the variances of amplitude of I channel and Q channel as follows [5]:

$$I = E|R_I|^2 + E|R_Q|^2, \tag{1}$$

where $E|\bullet|$ means expectation value. Desired signal S is archived by calculating the summation of the S_l from the 1 to L tap RAKE receiver.

Path loss and shadowing effects are regarded as slow fading in this paper. To compensate for slow fading, the CDMA2000 system has defined a standard equation for the mobile station to perform open-loop power control for the air interface in [6]. The general open-loop response of the open-loop power control can be approximated as follows:

$$O(t) = -\Delta P_{in}(1-\exp(-t/\tau))u(t), \quad (2)$$

where ΔP_{in} , τ, and $O(t)$ mean step change in mean input power, the time constant of the open loop response, and output. The OLPC output response of UE serving from ATC is close to that specified in the standards if τ is 20 *ms*. We assume that operation period of the OLPC output response of UE serving from GEO satellite is 250 *ms*. In this paper is added to monitoring equipment in OLPC to use information about the transmitting power that has not yet experienced by the receiver over satellite/ATC channel.

IV. CLOSED-LOOP POWER CONTROL

CLPC is a powerful tool to mitigate near-far problems in a DS-CDMA system over Rayleigh fading channels. The SAT/ATC advises the UE of adjustments to the transmitting power level that may have initially been set by open-loop power control. This form of power control (open- and/or closed-loop) may increase the UE's EIRP up to a maximum in order to maintain link connectivity and/or acceptable link quality. Because of a significant difference in the RTD, we have serious performance degradation of the CLPC if the power control used for the terrestrial interface is employed as is. In order to reduce power control error, a delay compensation mechanism was selected in the ATC and satellite.

V. SIMULATION RESULTS

A channel with only fast fading and a channel with path loss, slow fading, and fast fading were simulated to examine the performance of the closed-loop power control with and without an open-loop power control. In the simulation results, we present the simulation results according to application existence and nonexistence in Table I over GEO satellite or ATC environments, and compared the performance of the various conventional OLPC and CLPC algorithms. As the conventional schemes, we used the terrestrial CLPC scheme in the WCDMA system [7] and Gunnarsson's scheme in [4], and they are denoted as SCHEME-XII and SCHEME-VI in the figures. In reference, the part shown in the dotted line and solid line mean without pilot diversity and with pilot diversity, respectively. In our simulations, we consider a satellite system with a single beam and ignore the inter-spot interference. We assume that the path loss exponent is taken to be 2. For the simulations we chose a target SIR of 5 dB. We select the PG (processing gain) of 256. We assumed power control begin to work since 250 *ms* due to propagation delay.

Table 1 Application existence and nonexistence ("O" – applied, "X" – not applied).

SCHEME	Monitoring transmit power	Pilot diversity	OLPC	CLPC
SCHEME-I	O	O	O	O
SCHEME-II	O	O	O	X
SCHEME-III	O	O	Perfect	O
SCHEME-IV	O	X	O	O
SCHEME-V	O	X	O	X
SCHEME-VI	O	X	Perfect	O
SCHEME-VII	X	O	O	O
SCHEME-VIII	X	O	O	X
SCHEME-IX	X	O	Perfect	O
SCHEME-X	X	X	O	O
SCHEME-XI	X	X	O	X
SCHEME-XII	X	X	Perfect	O

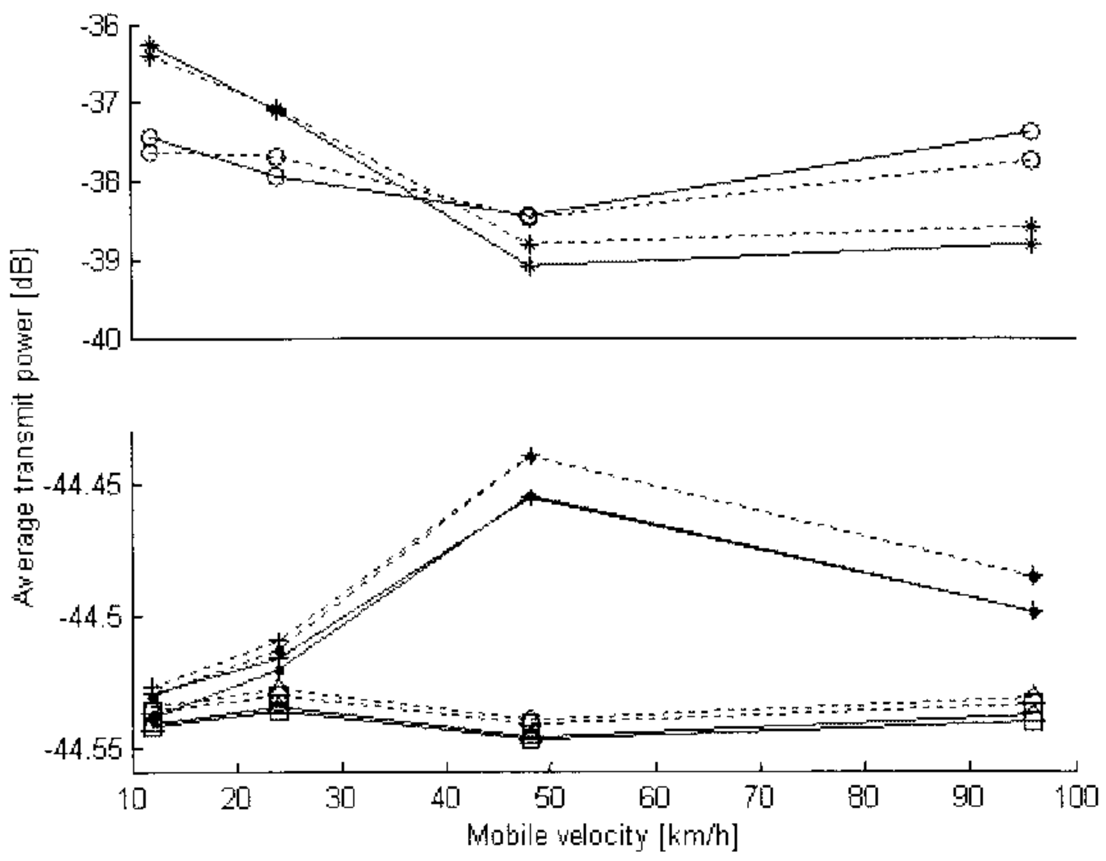

Fig. 4 Average transmit power of UE serving from ATC according to mobile velocity.

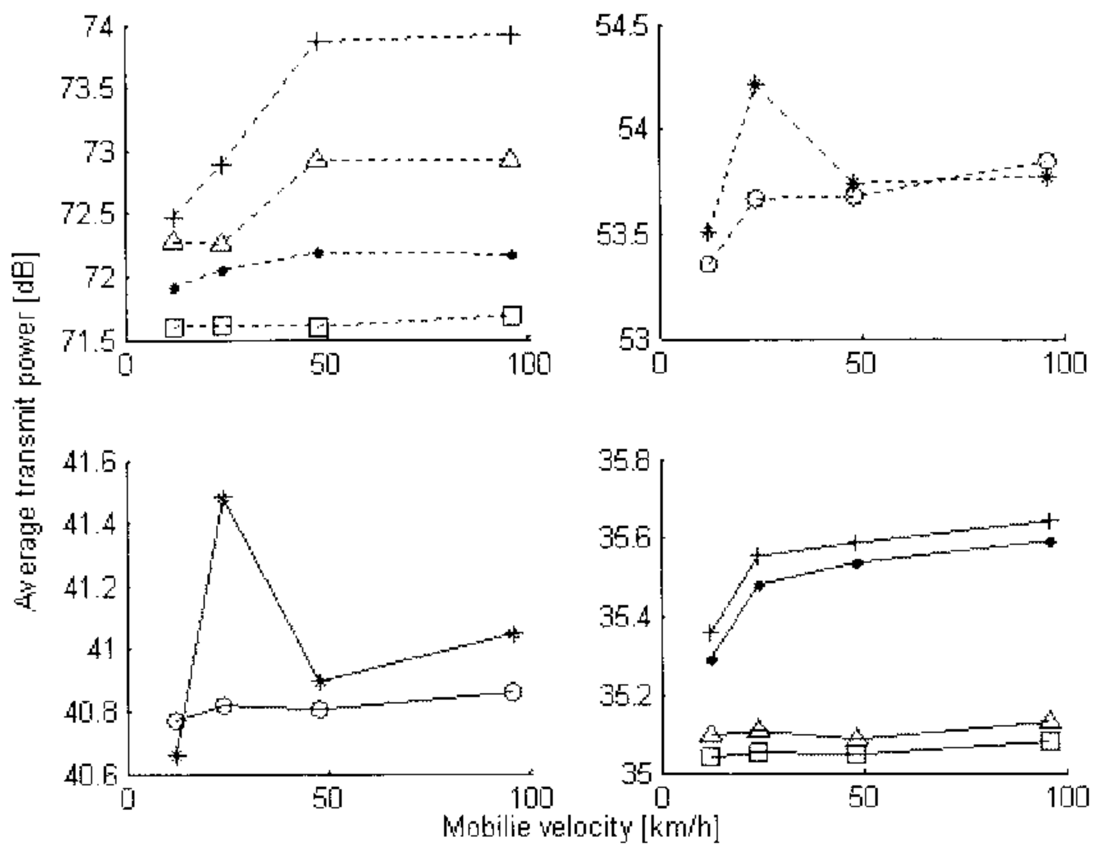

Fig. 5 Average transmit power of UE serving from GEO satellite according to mobile velocity.

Figures 4 and 5 show the average transmitting power consumed at the transmitters of specific users according to mobile speed. It is observed that average UE transmitted power of all schemes is dependent of mobile speed. However we can see that users with a combination of the modified- OLPC and CLPC scheme consume less power. It is also seen that at low vehicle speeds (<40 *km/h*), combining modified OLPC and modified CLPC (SCHEME-I with solid line) is very effective. This is because SCHEME-I with solid line compensates slow fading and path loss by monitoring transmitting power of UE simultaneously archives diversity gain by using efficient channel estimation algorithms.

Figure 6 and 7 show PDF (probability density function) of the received SIRs on condition mobile speed 98 *km/s* having probability of power control command error with 0. Intuitively, we turn out that the SCHEME-I using pilot diversity has a larger improvement, as confirmed in the simulation results.

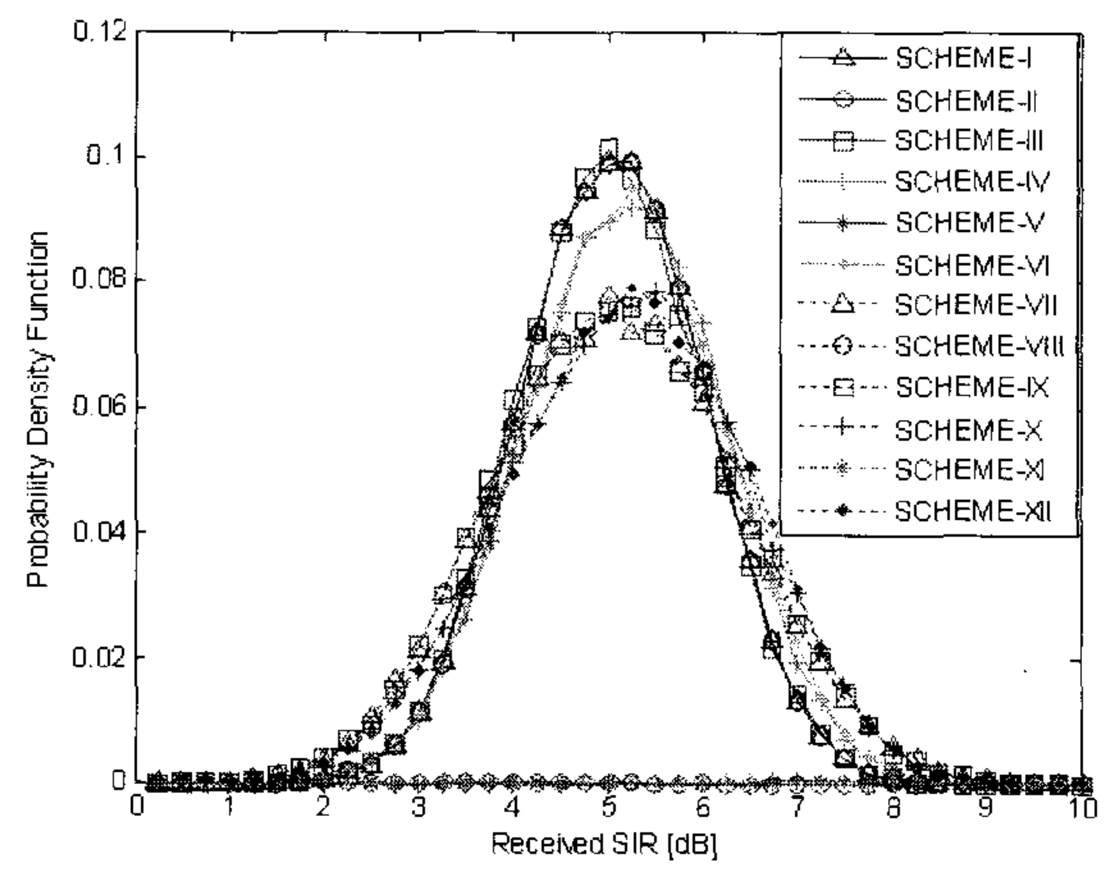

Fig. 6 Probability density function of received SIRs of UE serving from ATC: *K*=-inf and V=98 *km/h*.

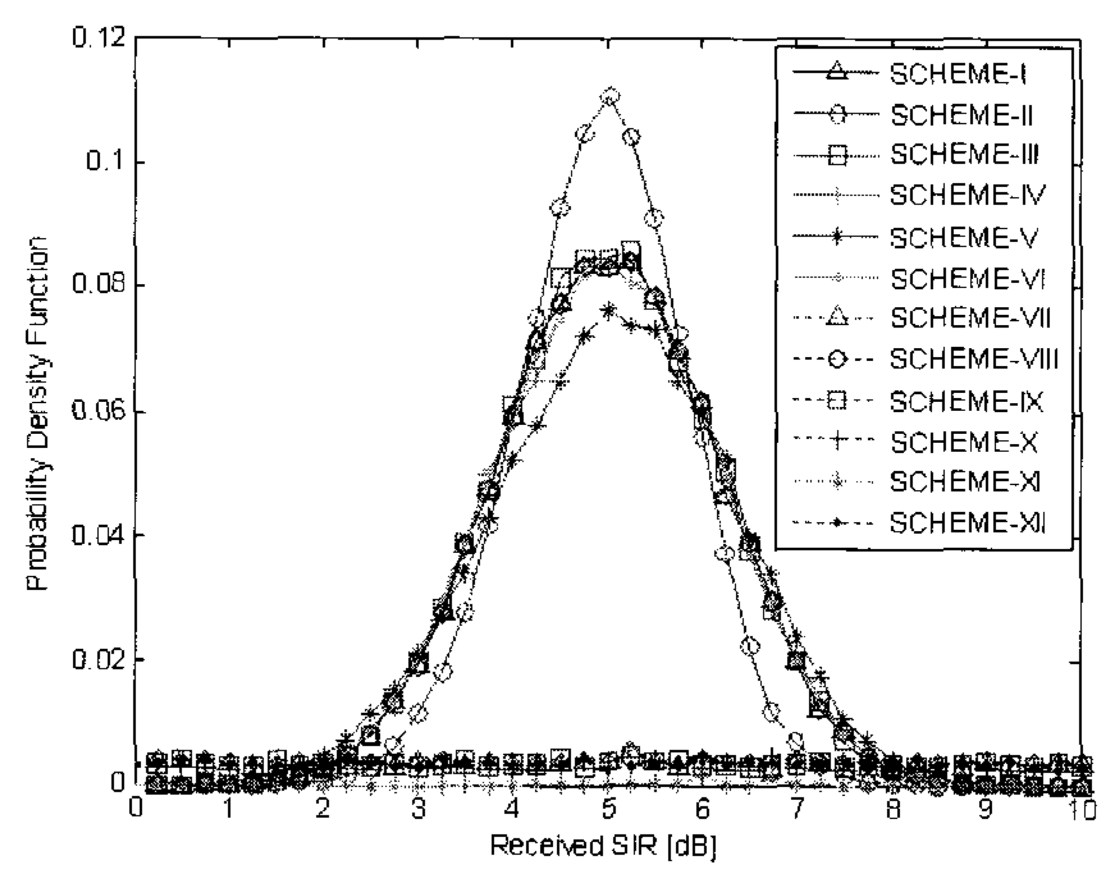

Fig. 7 Probability density function of received SIRs of UE serving from GEO satellite: *K*=5 dB and V=98 *km/h*.

VI. Conclusions

The conventional channel estimation methods incur many errors in the case of deep fading. On the other hand, since the inventive channel estimation method using the S-CCPCH to the conventional methods can obtain an improved pilot diversity gain by performing the channel estimation using other channels in the case when the first channel does not come up to a required level of a received signal, it is possible to implement an ideal maximum ratio combining method in a RAKE receiver. The channel estimation method described in this paper provides a more improved performance than channel estimation in a receiver of a terminal having conventional pilot symbols of a CPICH or a DPCCH by combining pilot symbols of a CPICH, a DPCCH, and a S-CCPCH (secondary common control physical channel), and estimating a channel. In this paper, we presented satellite access technologies for a future mobile system. We suggested desirable modifications for application to the 4G system. Combining modified CLPC and modified OLPC with delay compensation algorithms and monitoring equipment were proved to provide a good performance in a MSS/ATC hybrid system. In addition, not only to increase the performance but also to keep commonalities between 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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