# Broadband Packet Wireless Access Incorporating High-Speed IP Packet Transmission

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***Abstract***-This paper proposes broadband packet wireless access employing variable spreading factor-orthogonal frequency and code division multiplexing (VSF-OFCDM) in the forward link and multi-carrier(MC)/DS-CDMA in the reverse link for the system beyond IMT-2000. Based on wireless access schemes, we propose major radio air interface parameters in the physical layer to achieve our target maximum throughput beyond 100 Mbps and 20 Mbps in the forward and reverse links, respectively. We present key radio link control technologies such as adaptive radio link parameter control in the physical layer according to the QoS requirement and radio link conditions, random access channel based short and long packet transmission in the reverse link, and a weighted Maximum CIR (carrier-to-interference power ratio) scheduler with the assurance of the minimum throughput for accessing users in the forward link. Furthermore, we apply an incremental redundancy type hybrid automatic repeat request associated with turbo coding. Finally, computer simulation results elucidate that the VSF-OFCDM using the proposed radio link parameters achieves transmission above 100 Mbps with the average packet error rate of $10^{-2}$ at the average received signal energy per bit-to-background noise spectrum density ratio of approximately 7.3 dB.

## 1. INTRODUCTION

Commercial wideband-code division multiple access (W-CDMA) [1] services were launched in Japan in 2001, and its successive introduction is planned on a global scale. Furthermore, high-speed downlink packet access (HSDPA) based on the W-CDMA air interface is currently being discussed in the 3rd generation partnership project (3GPP) in order to offer high-rate data services above 2 Mbps [2]. HSDPA comprises such techniques as adaptive modulation and coding (AMC) in accordance with the radio link conditions, hybrid automatic repeat request (HARQ), and fast packet scheduling. However, a totally new wireless access scheme is needed for broadband packet transmission to achieve significantly higher data rates with a wide range of coverage. Anticipating the current and future increases in the amount of data traffic, forward link wireless access needs to establish broadband packet transmission with a maximum data rate above 100 Mbps using an approximate 50 to 100 MHz bandwidth [3]-[5]. The authors clarified that orthogonal frequency and code division multiplexing (OFCDM) which is originally based on multi-carrier CDMA (MC-CDMA) [6],[7], or orthogonal frequency division multiplexing (OFDM), exhibits better performance than conventional DS-CDMA based wireless access, due to mitigation of the degradation caused by severe multipath interference (MPI) in a broadband channel [3],[5]. Furthermore, we recently proposed OFCDM with variable spreading factor (VSF) packet wireless access (hereafter VSF-OFCDM) [8], which changes the spreading factor, $SF$, of OFCDM corresponding to the cell structure and radio link conditions, including the special no-spreading mode with $SF = 1$ (thus, OFCDM becomes OFDM). Through VSF-OFCDM, the seamless and flexible deployment of the same wireless access method both in multi-cell and single-cell environments is possible, while still achieving the maximum link capacity in the respective environments. Meanwhile, a maximum data rate which is much higher than that provided by W-CDMA, say above 20 Mbps, may be required in the reverse link. For reverse-link wireless access, we elucidated that the DS-CDMA approach achieves a greater link capacity utilizing coherent Rake combining with a dedicated pilot channel (D-PICH) associated with a coded data channel than the MC-CDMA and OFDM approach [3].

Therefore, by unifying our evaluations on the constituent techniques, this paper proposes broadband packet wireless access employing VSF-OFCDM in the forward link and multi-carrier(MC)/DS-CDMA in the reverse link as a promising wireless access candidate for the system beyond IMT-2000. In the rest of the paper, we first describe our proposed broadband packet wireless access. The major radio link parameters in the physical layer are proposed to achieve our target maximum throughput beyond 100 Mbps and 20 Mbps in the forward and reverse links, respectively, in Section 2. Furthermore, after briefly describing the handover scheme based on IP-based core network in Section 3, we present several proposed key radio link control technologies, such as adaptive ratio link parameter control in the physical layer according to the quality of service (QoS) requirement and radio resource allocation for efficient packet access in Sections 4 and 5, respectively. Finally, we present in Section 6 the computer simulation results to elucidate our proposed wireless access technologies.

## 2. BROADBAND PACKET WIRELESS ACCESS BASED ON VSF-OFCDM AND MC/DS-CDMA

We adopt asymmetric frequency division duplex (FDD) between the forward and reverse links to establish flexible and independent traffic assignment. The following wireless access schemes are applied to the forward and reverse links.

### 2.1 VSF-OFCDM with Two-Dimensional Spreading in Forward Link

Fig. 1 shows the concept of VSF-OFCDM employing two-dimensional spreading where the spreading factor, $SF$ (= $SF_{Freq} \times SF_{Time}$, where $SF_{Freq}$ and $SF_{Time}$ are the spreading factors in the frequency and time domains, respectively), both in the frequency and time domains, is varied based on the cell structure whether in multi-cell environments such as cellular systems or in isolated-cell environments such as hot-spot areas or indoor offices, and based on the propagation channel conditions such as delay spread, mobility of the user equipment, and other-cell interference level. As shown in Fig. 1, VSF-OFCDM employs $SF > 1$ in a multi-cell environment to achieve higher link capacity. This is because one-cell frequency reuse is possible for $SF > 1$ by introducing a cell-specific scrambling code in the frequency and time domains, and thereby we can expect a direct increase in the link capacity by employing sectorization. Furthermore, the near optimum $SF$ value over 1 is adaptively controlled according to the radio link conditions. This is because the achievable number of multiplexed codes, $C_{mux}$, highly depends on the inter-code interference arising from the destruction of orthogonality among multiplexed code channels due to frequency selective fading. In order to reduce the inter-code interference, a smaller $SF_{Freq}$ is desirable to maintain the orthogonality among multiplexed codes in the frequency domain, where a similar channel fluctuation is observed during the spreading duration in the frequency domain. In contrast, to decrease the impact of other-cell interference, a larger $SF$ value is desirable. Meanwhile, in an isolated-cell environment, we can expect that OFDM ($SF = 1$) achieves higher link capacity, since OFDM experiences no interference among multiplexed code channels even in a frequency selective fading channel. Therefore, employing VSF-OFCDM provides a solution to accommodate both OFCDM and OFDM modes, and achieves higher link capacity in both multi-cell and isolated-cell environments.

Table 1 summarizes the major radio link parameters for VSF-OFCDM. In order to establish wide coverage in a cellular environment, an approximate 100-MHz bandwidth is employed to achieve the maximum throughput over 100 Mbps based on the QPSK data modulation, which requires a lower signal-to-interference power

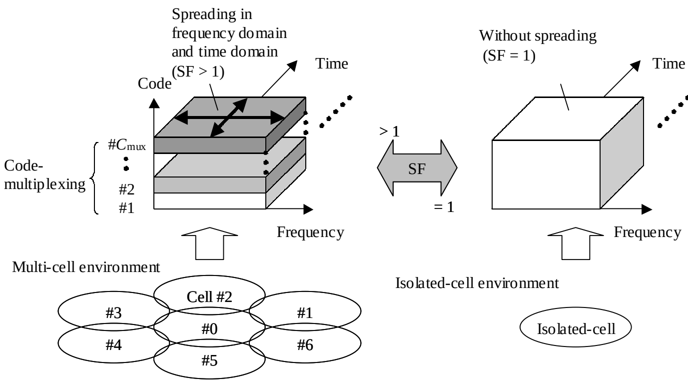



Fig. 1. Concept of VSF-OFCDM.

ratio (SIR) compared with multi-level modulation such as 16QAM. We utilize 768 sub-carriers for VSF-OFCDM with the sub-carrier spacing of 131.836 kHz, based on optimization to compensate for the maximum multipath delay time of up to 1.67 μsec and to avoid the influence of Doppler shift. The frame structure is shown in Fig. 2(a), with the frame length of 0.5 msec comprising 54 OFCDM symbols. Within a frame, we assign 48 data symbols to the downlink shared packet channel (DSPCH) or downlink dedicated packet channel (DDPCH), 2 symbols to the primary-pilot channel (P-PICH), and 4 symbols to the secondary-pilot channel (S-PICH) or D-PICH. Based on the above frame structure, when QPSK data modulation and the channel coding rate $R$ = 3/4 are applied associated with $C_{mux}$ = 15 code-multiplexing of $SF$ = 16, the achievable maximum throughput, $R_b$, becomes 103.68 Mbps. In the case of 16QAM data modulation with ($R$ = 1/2, $C_{mux}$ = 11) and ($R$ = 3/4, $C_{mux}$ = 8), the $R_b$ values are 101.376 Mbps and 110.592 Mbps, respectively. Furthermore, if we employ 64QAM data modulation with $R$ = 3/4 in the OFDM mode, i.e., $SF$ = 1, $R_b$ attains a throughput of over 300 Mbps in the proposed VSF-OFCDM air interface. In the forward link, we employ pilot channel assisted minimum mean squared error (MMSE) combining for signal despreading in VSF-OFCDM. In our proposal, the essential parameters needed for calculating MMSE combining weights, i.e., the channel gain of each sub-carrier, noise power, and transmission power ratio of all the code-multiplexed channels to the desired one, are estimated by utilizing the time-multiplexed pilot channel within a frame [9].

### 2.2 MC/DS-CDMA in Reverse Link

In contrast to the forward link, we elucidate that the DS-CDMA approach achieves higher link capacity using coherent Rake combining with a D-PICH than does using a large number of multi-carriers, such as MC-CDMA and OFDM [3],[5]. The DS-CDMA approach is also advantageous in the application to the reverse link, owing to lower power consumption for its inherently much lower peak-to-average power ratio (PAPR) feature compared with MC-CDMA and OFDM accompanying a large PAPR causing an increase in the back-off of the power amplifier. Furthermore, to avoid unexpected extraordinary interference and for spare usage, the DS-CDMA, employing at least several sub-carriers where each has the optimum bandwidth to maintain the required quality, is the most appropriate solution. Therefore, we optimized the sub-carrier bandwidth of MC/DS-CDMA in the reverse link to around 20 to 40 MHz, for various channel models, from the tradeoff between the improvement in the Rake time diversity effect and the degradation due to increasing MPI [10]. Thus, in our proposal, as shown in Table 2, the reverse link MC/DS-CDMA consists of 2-sub-carriers each with a 20-MHz bandwidth. As shown in Fig. 2(b), the frame length is 0.5 msec where the D-PICH and uplink dedicated packet channel (UDPCH), comprising the uplink dedicated packet data channel (UDPDCH) and uplink dedicated packet control channel (UDPCCH), are code-multiplexed in a frame. Based on this frame structure, when QPSK data modulation with $R$ = 3/4 and $C_{mux}$ = 2 code-multiplexing of $SF$ = 4, the achievable maximum throughput, $R_b$, becomes 24.576 Mbps.

Table 1. Radio link parameter (Forward link).

| | |
|---|---|
| Wireless Access | VSF-OFCDM |
| Bandwidth | 101.5 MHz |
| Number of sub-carriers | 768 (131.836 kHz spacing) |
| OFCDM total symbol duration | 9.259 $\mu$sec (including 1.674 $\mu$sec guard interval) |
| Frame length | 54 OFCDM symbols (0.5 msec) (P-PICH: 2, S-PICH/D-PICH: 4, DTCH: 48) |
| Data modulation | QPSK, 16QAM, 64QAM |
| Channel coding (Turbo coding) rate | 1/3 – 5/6 |
| Spreading factor | 1 – 256 |

Table 2. Radio link parameter(Reverse link).

| | |
|---|---|
| Wireless Access | MC/DS-CDMA |
| Bandwidth | 40 MHz |
| Number of sub-carriers | 2 (20 MHz spacing) |
| Chip rate per sub-carrier | 16.384 Mcps (Roll-off factor: 0.22) |
| Frame length | 8192 chips/sub-carrier (0.5 msec) |
| Data modulation | QPSK, 16QAM, 64QAM |
| Channel coding (Turbo coding) rate | 1/3 – 5/6, 1/16 |
| Spreading factor | 1 – 256 |

## 3. HANDOVER BASED ON IP CORE NETWORK

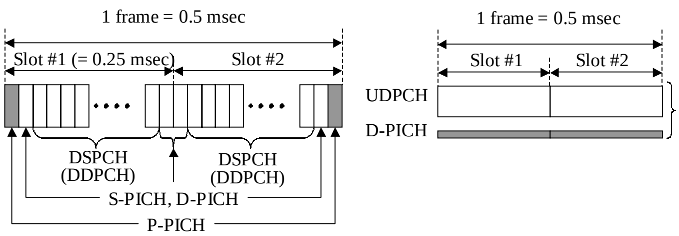
The core network in broadband packet wireless access for the system beyond IMT-2000 will certainly be based on an all-IP-based network as shown in Fig. 3. Thus, the radio network controller in the W-CDMA system, which performs the inter-cell soft handover function, will be replaced by an IP-router in the system beyond IMT-2000. Therefore, from the viewpoint of the control signaling between base stations including the router, hard handover is more desirable than soft handover containing fast cell selection (FCS) in the forward link. Additionally, as the bandwidth becomes broader, the effect of FCS on yielding the instantaneous fading variation is considered to decrease. Nevertheless, the inter-cell and inter-sector macro diversity by cell selection, which tracks the shadowing variation, is effective. Therefore, inter-cell and inter-sector cell selection in the forward link to track shadowing variation is preferable.

## 4. ADAPTIVE RADIO LINK CONTROL

HARQ in Layer 2 is essential for high-quality packet transmission especially for non-real time (NRT) traffic data, since error-free transmission must be guaranteed for packet data services. HARQ complementarily works along with AMC because the packet errors caused by false selection of modulation and coding scheme (MCS) due to the estimation errors of radio link conditions are mitigated. As the bandwidth becomes much broader, the incremental redundancy method is more effective since the received signal level for the total bandwidth approaches a static channel. Thus, it is considered that the superiority of incremental redundancy, i.e., Type-II HARQ to Chase combining (Type-I hybrid ARQ with packet combining) derived by code combining, is increased in a broadband channel.

Fig. 4 shows the proposed concept of adaptive radio parameter control considering the QoS class [11]. Although the AMC is adopted in HSDPA, MCS selection in the conventional AMC only considers the received signal quality, such as the received SIR. However, this is insufficient for supporting various QoS requirements, since the radio link parameters in the MCS strongly depend on not only the received SIR, but also on the QoS requirements, especially the tolerable packet transmission delay. Therefore, our proposal is an adaptive radio parameter control that considers the QoS requirements, that is to say, we propose to introduce a delay requirement, i.e., maximum number of packet retransmissions, $M$, in HARQ, in addition to the conventional MCS, and to employ a different radio parameter set according to the QoS requirements.

In the figure, the traffic class classifier detects the QoS class of the data packet to be transmitted. Then, the appropriate radio link parameters such as data modulation, channel coding rate, spread-




(a) Forward link. (b) Reverse link.

Fig. 2. Frame structure.

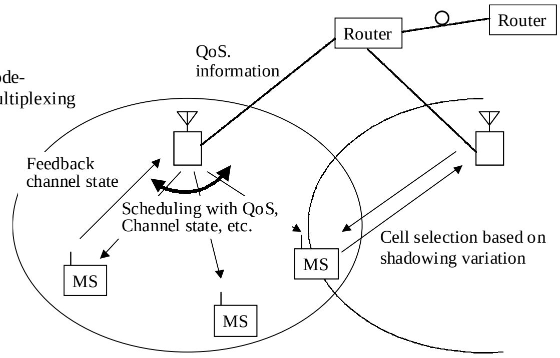



Fig. 3. Network structure.

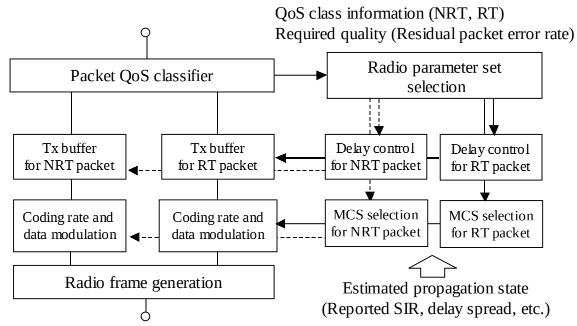
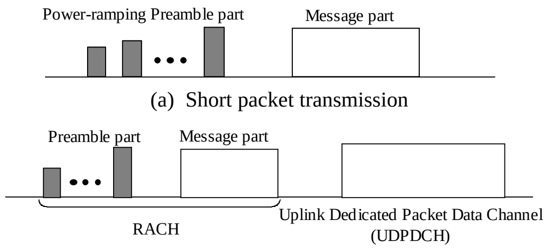



Fig. 4. Adaptive radio parameter control with QoS class.




(a) Short packet transmission

(b) Long packet transmission

Fig. 5. Efficient packet access in reverse link.

ing factor, and the number of code multiplexing are selected based on the QoS requirements. Concretely, in NRT class data, data packets decoded with packet errors are retransmitted until they are received without errors, that is we set $M = \infty$, because extremely high reliability is needed allowing a long delay. Meanwhile, since the delay requirements for real time (RT) traffic are very strict, the maximum number of retransmissions in RT class data is restricted by the round trip delay in the HARQ. Thus, the maximum number of retransmissions may be approximately several times for RT traffic. Furthermore, in the forward link VSF-OFCDM, the optimized *SF* is selected to match the long-term averaged link conditions, considering the delay spread of the propagation channel and the other cell interference levels as described in the Section 2.

## 5. RADIO RESOURCE ALLOCATION FOR EFFICIENT PACKET ACCESS

### 5.1 Random Access and Reservation Type Long Packet Transmission in Reverse Link

Fig. 5 shows the proposed short and long packet transmission schemes. In the reserve link, short packet data are transmitted by a random access channel (RACH). The RACH comprises a power-ramping preamble part and a message part similar to the W-CDMA air interface, because the preamble with power ramping is an effective technique in reducing the interference to other accessing users. The preamble indicates the received timing and the channelization code of the subsequent message part. Furthermore, in our proposed scheme, the QoS of the subsequent message part is pre-indicated by the layered signature configuration of the preamble signature or control (indication) signal within the message part.

A long packet carrying a large amount of information data is transmitted by the UDPDCH associated with each accessing user. Thus, we unify the random access-type short packet transmission and reservation-type long packet transmission together. That is, the message part of the RACH is used as a reservation packet, which conveys the received timing, channelization code, packet data size, and QoS information of the subsequent UDPDCH.

### 5.2 Fast Packet Scheduling Algorithm in Forward Link

Three packet-scheduling algorithms are investigated for HSDPA in 3GPP: Maximum CIR (carrier-to-interference power ratio), round robin (RR), and proportional fairness (PF) schedulers. In the Maximum CIR scheduler, the base station assigns a slot to the accessing user with the highest received SIR with priority based on the reported received SIR values from all access users. Thus, the total throughput with the Maximum CIR method is higher than that with the other algorithms, since it increases the advantage of employing AMC. However, unfairness in the slot assignment occurs since the packet transmission is seldom assigned to the accessing user with a lower received SIR. Our proposed packet scheduling is based on the weighted Maximum CIR, however, the minimum number of opportunities for all accessing users is assured regardless of the received SIR condition of each user in order to solve the unfairness problem. Comparing our proposed method to the PF method, the total system throughput is increased since our method places priority on the accessing user with a higher received SIR.

## 6. SIMULATION RESULTS

The VSF-OFCDM performance in the forward link wireless access is clarified in a broadband multipath fading channel. At the transmitter, binary information data bits per packet are encoded by turbo coding with $R$ and the constraint length of $K = 4$ bits and data modulated. Then, each symbol is spread over $SF = SF_{Freq} = 16$ sub-carriers by the combination of an orthogonal short code sequence with a repetition period of $SF = 16$ chip length, and a scrambling code with the repetition interval of the number of sub-carriers, $N_c = 768$. A Walsh-Hadamard code and a long pseudo-random code are used for the short code and scrambling code, respectively. After code-multiplexing the $C_{mux}$ code-channels into DSPCH (or DDPCH) and time multiplexing with pilot symbols within a frame, the inverse fast Fourier transform (IFFT) generates OFCDM symbols with $N_c = 768$ sub-carriers. The resultant frame contains 48 coded data and (4+2) pilot OFCDM symbols, respectively.

At the receiver, the auto-correlation between the effective symbol interval and the guard interval is calculated every OFCDM symbol and the correlation value is further coherently averaged over a frame, i.e., a 54 OFCDM-symbol duration. Thus, the OFCDM symbol is synchronized to the timing yielding the maximum correlation peak. After the guard interval is removed based on the estimated OFCDM symbol timing, the OFCDM signal is de-multiplexed into each sub-carrier component by the fast Fourier transform (FFT). In order to despread the signals in the frequency do-

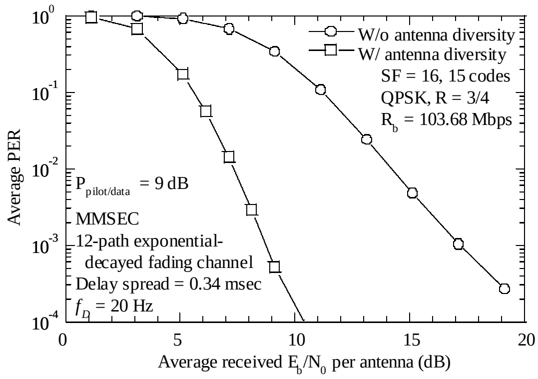



Fig. 6. PER performance.

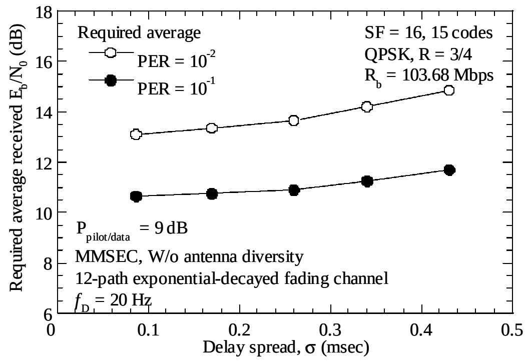



Fig. 7. Impact on r.m.s. delay spread.

main, we apply the MMSE combining algorithm based on the pilot symbol-assisted channel estimation and interference power estimation in the despreading [9]. Finally, the despread sequences are serial-to-parallel-converted and turbo decoding is performed using Max-Log-MAP decoding with 8 iterations to recover the transmitted binary data.

We assume an exponential decay multipath fading channel comprising 12 paths, in which each path suffers from independent Rayleigh fading. Fig. 6 shows the average packet error rate (PER) performance as a function of the average received signal energy per bit-to-background noise power spectrum density ratio ($E_b/N_0$) per antenna without and with 2-branch antenna diversity reception. The r.m.s. delay spread, $\sigma$, was assumed to be 0.34 μsec. For antenna diversity reception, we applied diversity combining with equal gain combining after despreading in the frequency domain employing MMSE combining. Fig. 6 clearly shows that even for 15-code multiplexing, no error floor due to inter-code interference is perceived. Taking into account the application of HARQ where almost error-free transmission is realized under the average PER = $10^{-2}$, we find from Fig. 6 that the required average received $E_b/N_0$ is approximately 7.3 dB with antenna diversity reception, which indicates the realization of over 100 Mbps throughput in VSF-OFCDM packet wireless access. Next, the average received $E_b/N_0$ of the 103.68-Mbps transmission at the average PER of $10^{-2}$ and $10^{-1}$ is plotted in Fig. 7 as a function of $\sigma$. The figure shows that even when $\sigma$ = 0.43 μsec (note that the maximum delay time becomes 1.63 μsec in this case), the increase in the required average received $E_b/N_0$ from that with $\sigma$ = 0.09 μsec is slight, indicating the enduring property of VSF-OFCDM against the delay spread. Finally, the throughput performance using QPSK, 16QAM, and 64QAM data modulation with $R$ = 1/2 and 3/4 in OFCDM is plotted in Fig. 8 as a function of the average received signal energy per symbol-to-background noise power spectrum density ratio ($E_s/N_0$). It was assumed that $SF$ = 16, $C_{mux}$ = 12, and $\sigma$ = 0.34 μsec. Fig. 8 clearly indicates that the throughput above 100 Mbps is possible employing 16QAM modulation with $R$ = 1/2 at the average received $E_s/N_0$ of 9 dB with antenna diversity reception.

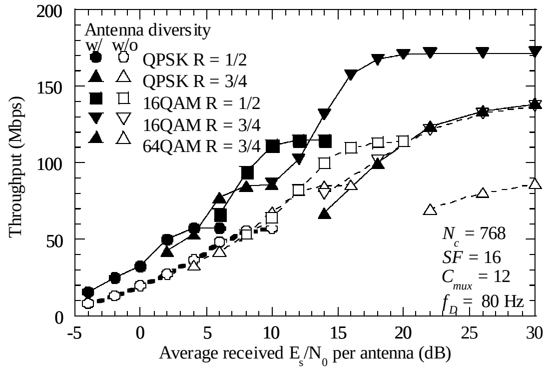



Fig. 8. Throughput performance.

## 7. CONCLUSION

This paper proposed broadband packet wireless access employing VSF-OFCDM in the forward link and MC/DS-CDMA in the reverse link for the system beyond IMT-2000. Based on wireless access schemes, the major radio air interface parameters in the physical layer were proposed to achieve our target maximum throughput beyond 100 Mbps and 20 Mbps in the forward and reverse links, respectively. We presented key radio link control technologies such as adaptive ratio link parameter control in the physical layer according to the QoS requirement, RACH based short and long packet transmission in the reverse link, and a Weighted Maximum CIR scheduler with the assurance of the minimum throughput for access users in the forward link. Furthermore, we applied incremental redundancy type HARQ associated with turbo coding and AMC scheme. Finally, computer simulation results elucidated that the VSF-OFCDM using the proposed radio link parameters achieved a transmission above 100 Mbps with the average packet error rate of $10^{-2}$ at the average received $E_b/N_0$ of approximately 7.3 dB.

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