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# IP-Based Transmission on Third-Generation Wireless (IMT-2000) and Beyond

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**The future-generation mobile communication systems, including the third-generation mobile radio systems (IMT-2000) and the systems beyond IMT-2000, are expected to provide a wide variety of services compatible with those available on the Internet. The radio access networks should be optimized for high-speed IP packet transmission with a QoS provision and efficient spectrum utilization. This paper describes the requirements for such radio access networks and some novel technologies for realizing efficient packet transmission. Functional requirements in the data link layer for transmission of heterogeneous IP traffic with different QoS requirements are described. For the radio access technologies, two novel spatial processing techniques for efficient packet transmission are proposed. One is an advanced path searcher with a direction-of-arrival estimation capability for IMT-2000 base stations which employ an adaptive array antenna. The other is a closed-loop transmit diversity technique with a beam-forming capability. This paper shows that both techniques can improve the system capacity and reduce the required transmission power.**

## 1. Introduction

The third-generation (3G) cellular networks (IMT-2000) will be able to support a large variety of multimedia services and high rates of data transmission (384 kb/s wide-area coverage, up to 2 Mb/s local coverage).[1] The first release (Release-99) of the specifications became ITU-R-standard in 2000, and the world's first W-CDMA commercial service was launched in Japan in May 2001. The current core network is based on a circuit-switched architecture similar to the second-generation cellular networks. For future releases of the 3G specifications, the 3GPP/3GPP2 (3rd Generation Partnership Project/3rd Generation Partnership Project 2) is focusing on developing standards for all-IP networks. Because of the tremendous popularity and ubiquity of IP networks, there have been ongoing efforts to utilize IP over wireless links to form end-to-end IP networks. In such a utilization of IP technology, deployment of IP mobility control schemes (e.g., Mobile-IP) and IP QoS management schemes will be important issues to consider. Such networks can simplify development and deployment of different QoS schemes.

The concept and development of systems beyond IMT-2000 are already being discussed. Further enhancements of current IMT-2000 systems have been discussed in the 3GPP/3GPP2 to provide higher capacities and advanced IP-based network functionalities and services.[2] These evolved core and radio access networks will migrate to future advanced systems. Depending on future user requirements and economic demands, new radio access systems — fourth-generation (4G) systems — will be developed (**Figure 1**). Fourth-generation systems are characterized by their support of high transmission rates of around 20 Mb/s per user, high mobility, end-to-end IP transmission, and QoS management.[3] The new

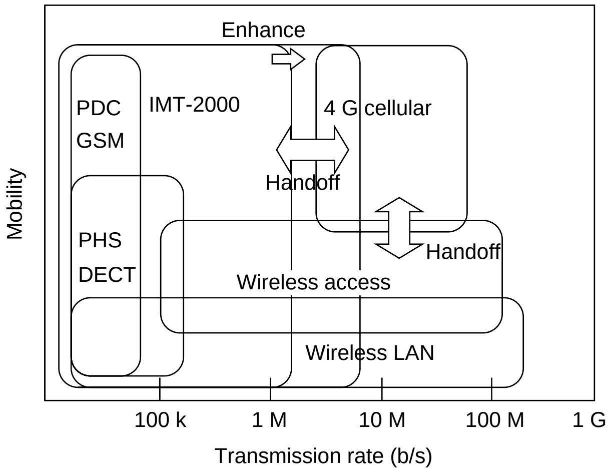


Figure 1
Mobile communications systems.

4G access network and other access systems will be connected to a common, access-independent, flexible, and seamless IP-based core network. For the radio interface for the 4G access technology, although a variety of modulation/access schemes have been studied so far, multi-carrier modulation techniques such as OFDM are considered to be among the most promising candidates due to their robustness against multi-path radio propagation and their spectral efficiency.

In this paper, we discuss the requirements for realizing efficient IP data transmission over cellular networks of IMT-2000 and beyond and propose several new technologies for realizing it. We are not concerned here with the IP mobility issues, as they are described in detail in Reference 4). In this paper, we will focus on the study of the data link layer (DLC) requirements and the radio transmission technologies for realizing a high transmission rate with a high spectrum efficiency and reliable radio channels, especially for downlinks suitable for broadband IP transmission.

This paper is organized as follows. First, Section 2 gives an overview of the packet mode in IMT-2000 being discussed in the 3GPP/3GPP2. Then, Section 3 gives an outline of the required DLC functionalities for IP packet transmission with QoS provision. Then, Section 4 proposes several novel technologies for efficient packet transmission: a new, fast path-search scheme suitable for adaptive array antennas and a novel downlink transmit diversity scheme. Finally, Section 5 gives our concluding remarks.

## 2. Packet mode in wireless networks

The CDMA-based air interfaces of W-CDMA and cdma2000 were originally designed for circuit-based communications. However, further extensions for efficient packet transmission have been discussed and specified in the 3GPP/3GPP2. In the 3GPP, high-speed downlink packet access (HSDPA) can attain a peak transmission rate of about 10 Mb/s in the downlink. Mixed usage of voice and packet data transmission is allowed in HSDPA. The techniques employed to improve the capacity and data throughput are as follows:

- Adaptive modulation and coding (AMC). This is a technique for adapting the modulation and coding format based on the received signal quality and channel conditions. Users close to the base station are typically assigned a higher-order modulation with higher code rates, but the modulation order and code rate decrease as the distance from the base station increases. This requires feedback from the receiver about the signal quality.
- Hybrid ARQ. ARQ is an indispensable functionality for error-free data transmission and is usually handled in the TCP layer to establish reliable end-to-end link communication. When a wireless link is used in a part of the connection, frequent retransmissions between hosts due to transmission errors reduces the throughput and delay performance. Additional local ARQ in the wireless link will mitigate this problem. Hybrid ARQ is a technique that combines ARQ with forward error correction (FEC) functionality. FEC decoding using soft-combination of retransmitted data with the data transmitted first can improve the error correction

performance and reduce the number of retransmission attempts.

- Fast cell site selection (FCSS). To receive a frame, a mobile station selects the cell site that is best able to transmit the required data and then requests the selected cell site to transmit it. The other cells which are not selected by mobile stations switch off their transmitters. This process is repeated every frame.

Similar technologies are employed in the cdma2000 1x -DO (1x data-only) system. These advanced high-speed packet channels can offer broadband wireless Internet access.

## 3. DLC functionality required for IP QoS

The next generation of mobile networks must be able to support multimedia services having a wide range of traffic characteristics and quality of service (QoS) requirements.[5] For the wired Internet, QoS provisioning mechanisms that use technologies such as queue management, scheduling, and shaping/policing have been extensively discussed in the IETF (Internet Engineering Task Force) and have been employed in current commercial IP routers.

However, some functional enhancements will be required to apply these mechanisms to wireless IP networks. Most of these enhancements will be needed because of certain properties of wireless channels, for example, their high error rates, limited capacity, link adaptation capability, and need for interference/power management.[6] **Figure 2** shows a packet scheduler model for a wireless link with link adaptation and lists the control parameters used in the model. Some requirements for the packet scheduling and admission control are discussed in the following sections.

### 3.1 Packet scheduling

In wireless networks, the packet scheduler functions as a radio resource manager as well as providing the required QoS. Besides the QoS parameters, the "channel-aware" scheduling algorithm operates according to various radio channel resource parameters, for example, the SIR, available rate, and speed of the mobile station. The choice of scheduling algorithm determines the trade-off between the total throughput and fairness, which is the extent to which radio resources are shared fairly between packets. For example, an algorithm that transmits to users at maximum SIR can achieve a high total throughput but reduces the fairness. Round robin scheduling emphasizes fairness. To attain a higher throughput and efficient use of radio resources, unfair scheduling would be a better choice.

For CDMA systems, the effect of abruptly changing loads should be investigated and taken into account since these could cause instabilities in the network, especially when voice and data users share the same spectrum. The sudden transmission of high-power data packets will cause significant additional interference in the local sector and other sectors. This will cause a transient or possibly longer lasting reaction in the transmit power control mechanism of each user, further increasing interference.

### 3.2 Call admission control

Admission control is performed based on user and call priority information. Certain users who pay an extra fee will have a higher priority.

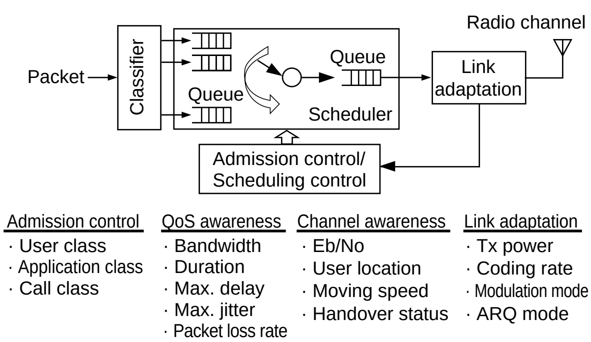


Figure 2
Scheduler model for a wireless link.

Hand-over calls from other cells will have a higher priority, and best-effort calls will have the lowest. Although it will be difficult to maintain the required bandwidth for hand-over calls in the new cell, the required bandwidth for the guaranteed services can be maintained across the hand-over by taking resources from the best-effort calls. Thus, calls with low priority may be degraded. Some channel resources can be reserved for potential hand-over calls to mitigate the impact on the low-priority calls and to provide a more continuous service to mobile users. When neighboring cells have different channel capacities, it will be difficult for small-capacity cells to reserve enough resources for hand-over calls. In this case, all available resources should be allocated for these calls to maintain the communication link, though the required QoS will not be achieved.

## 4. Transmission technologies

In this section, we propose several radio transmission technologies which can improve the capacity of high-speed packet access channels.

### 4.1 Adaptive array antenna

The adaptive array antenna is considered to be a key technology for increasing capacity and reducing the transmission power of mobile stations in broadband wireless access systems.[7),8)] In CDMA systems, multi-user interference due to insufficient orthogonality between spreading codes reduces the cell capacity.

When designing an adaptive array antenna system for IP packet transmission and reception, there are two important issues to be considered. One is that increasing the number of antenna elements reduces the received signal-to-interference and noise ratio (SINR) at each antenna element. When only the received signal at one particular element is used for path searching, the performance gain expected from an adaptive array antenna will be reduced due to the degraded path search capability.

Another drawback of using an array antenna for packet transmission is its slow convergence of array weights. Ideally, the array weights should be converged before the first captured packet is demodulated. However, this is not possible if the pilot signal added to the message data is used for the weight calculation. In addition, the convergence speed of the adaptive algorithm is usually not enough to capture the short 10 ms packet.

We propose a new path searching scheme called 2-dimensional (2-D) path searching. This scheme has a quick direction-of-arrival (DoA) estimation capability as well as an improved channel delay profile estimation capability. **Figure 3** shows a block diagram of a base station receiver with a 4-element adaptive array antenna receiver and the proposed 2-D path searcher. In the proposed scheme, the DoA of each path is estimated by calculating the phase shift between received signals at the adjacent antenna elements. By combining all of the power-delay profiles obtained from the received signals at the array elements, the search performance of path timing can be improved.

In the uplink of the W-CDMA system, the random access channel (RACH) and common packet channel (CPCH) have been declared suitable for packet transmission.[9)] Before transmitting the RACH/CPCH message part, a mobile station

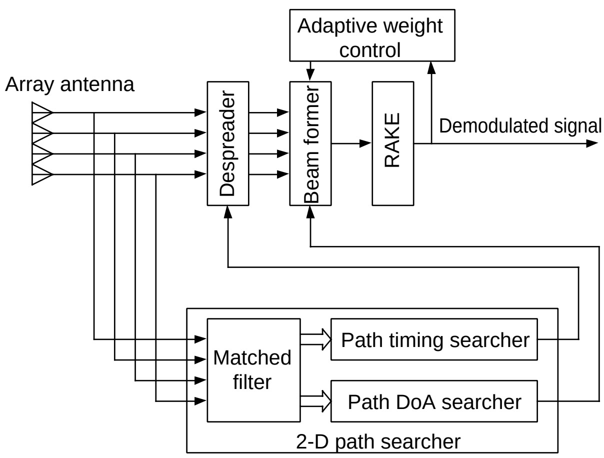


Figure 3
Receiver structure with 4-element adaptive array antenna and 2-D path searcher.

transmits a preamble 4096 chips long until it receives an ACK message from the base station. We evaluated the performance of the proposed 2-D path searcher for a W-CDMA RACH. Because the path-timing search and the DoA estimation are performed simultaneously by using the preamble part, the following RACH message part can be received using beam-forming gain. **Table 1** shows the system parameters used in the computer simulation.

**Figure 4** shows the preamble detection probability in terms of the average received chip power to noise ratio (Ec/No). At a preamble detection probability of 0.5, the proposed scheme (4AA) demonstrates an approximately 4.5 dB improvement over a scheme using a single antenna signal (1A) and an approximately 2.0 dB improvement over a scheme using two diversity branch signals (2SD). As a reference, the performance of the proposed scheme with an ideal profile that was created using known DoA information is also shown.

Table 1
Simulation parameters.

| | | |
|---|---|---|
| Chip rate | | 3.84 Mc/s |
| Preamble | Signature | Hadamard code |
| | Scrambling | Gold code ($2^{25}$–1) |
| Channel model | Delay profile | ITU-R Vehicular-B (fd = 80 Hz) |
| | Direction of arrival | Uniform distribution in sector |
| Antenna | | Linear array (Separation = 1 λ) |
| Path search | Resolution | 0.25-chip |

**Figure 5** shows the histogram of phase estimation errors after preamble detection. A total of 1000 trials were performed at Ec/No = –25.0, –27.5, –30.0, and –32.5 dB. In all cases, a beam-forming gain larger than 3 dB was obtained. This estimated DoA information can be used to adjust the initial beam-former weights to capture the RACH/CPCH message part following the detected preamble.

The dedicated channel, DCH, will be efficiently used for applications that require frequent packet transmission instead of using RACH/CPCH. For DCH, the power control preamble can be used for synchronization and for convergence of the closed-loop transmission power control. This power control preamble can also be used to estimate the initial antenna weights for capturing the following data part using the proposed scheme.

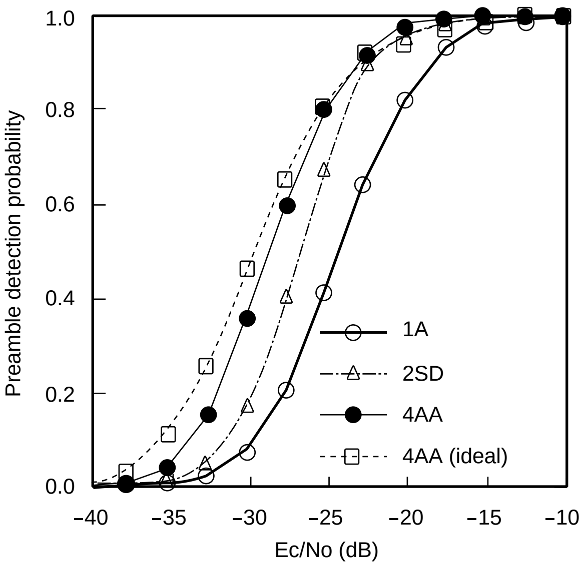


Figure 4
Preamble detection probability.

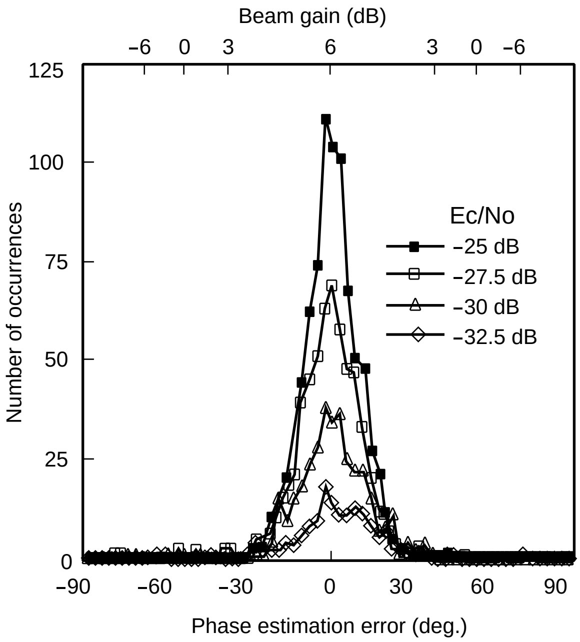


Figure 5
Phase estimation error performance.

## 4.2 Transmit antenna diversity

In IP networks, the traffic flow is very asymmetrical, the dominant traffic being the downlink data from servers to mobile users. Wireless links should therefore efficiently support such asymmetrical transmission. Improved usage of downlink resources will be a crucial point here. Advanced spatial signal processing techniques such as transmit antenna diversity, space-time coding, and downlink beam forming can improve the downlink capacity with little increase in the complexity of mobile stations. In this section, we discuss some closed-loop transmit antenna diversity schemes with beam-forming capability and propose our solution.

Due to the space limitations at antenna installation sites, the number of diversity branches for one sector will be limited to four or less. However, this is not a serious restriction because the diversity gain achieved by increasing the number of branches tends to reach a limit, especially when Rake combination and receiver antenna diversity are used in mobile stations. A combination of transmit diversity and downlink beam forming will be a flexible solution for certain applications such as high data rate packet transmission. It is generally understood that high data rate transmission is targeted at quasi-static mobile stations. Therefore, the beam-forming weights can be updated at a lower rate than that of the diversity, which can lead to an increase in the diversity gain under moderately fast fading conditions.

We propose a new multiple antenna transmit diversity scheme with a beam-forming feature. The proposed scheme supports a variety of antenna configurations and beam-forming algorithms to achieve an efficient transmitter diversity/beam-forming gain according to the spatial correlation characteristics. Based on the transmitter antenna configuration of the base station, mobile stations calculate short-term diversity weights and long-term beam-forming weights and then signal them to the base station in the appropriate feedback frame format. Three transmit diversity/beam forming scenarios for typical transmitter antenna configurations at the base station are considered below:

- A space diversity antenna array with a large inter-element spacing (larger than the spatial coherence length). For large angular spread environments, this might be a likely configuration. The same array can be used for uplink diversity reception at the base station. However, the large physical space required to locate multiple antenna elements will not be attractive.
- An antenna array with a small inter-element spacing (less than the spatial coherence length). In this configuration, the spatial correlations between antenna elements are high and the configuration is sufficient to achieve beam-forming. This configuration can be used for environments with a small angular spread. The same array can be used for uplink beam-forming at the base station.
- A space diversity array in which each diversity branch consists of a sub-array antenna. This configuration is suitable for environments with a small spread angle and it will be a practical configuration for the following reasons. Firstly, combined diversity and beam-forming can be applied in both the uplink and downlink. Secondly, open-loop transmit diversity such as STTD encoding[9] can be applied to the downlink common control channels.

We will now discuss the proposed algorithm in more detail. Consider an $M$ sub-array configuration in which each sub-array consists of $K=N/M$ elements, where $N$ is the total number of antenna elements. Firstly, the mobile stations find an $M$-dimensional short-term diversity weight vector $\underline{w}_D$ which maximizes the following:

$$P_D = \underline{w}_D^H H_D^H H_D \underline{w}_D \qquad (1)$$

with $H_D = [\underline{h}_1, \underline{h}_{K+1}, \cdots, \underline{h}_{(M-1)K+1}]$,

where $\underline{h}_{(m-1)K+1}$ $(m=1 \cdots M)$ is the channel response vector, which represents the $m$-th sub-array.

Secondly, the mobile stations find a $K$-dimensional beam-forming weight vector $\underline{w}_{B,m}$ for each sub-array which maximizes the following:

$$P_{B,m} = \underline{w}_{B,m}{}^{H} H_{B,m}{}^{H} H_{B,m} \underline{w}_{B,m} \quad (2)$$

with $H_{B,m} = [\underline{h}_{(m-1)K+1}, \underline{h}_{(m-1)K+2}, \cdots, \underline{h}_{(m-1)K+K}]$,

where $\underline{h}_{(m-1)K+k}$ ($k$=1⋯$K$) is the channel response vector of the $k$-th element in the $m$-th sub-array.

Then, short-term diversity weights $D_{1,m}$ and long-term beam-forming weights $B_{m,k}$ for the hierarchical weighting are calculated from $\underline{w}_D$ and $\underline{w}_{B,m}$ as follows:

$$D_{1,m} = \frac{w_D(m)}{w_D(1)} \quad (m = 1 \cdots M) \quad (3)$$

$$B_{m,k} = \frac{w_{B,m}(k)}{w_{B,m}(1)} \quad (m = 1 \cdots M,\ k = 1 \cdots K) \quad (4)$$

$\{D_{1,m}\}$ correspond to the $M$-branch transmit diversity weights, and $\{B_{m,k}\}$ are the beamformer weights for the $m$-th antenna group. The feedback frequency for $\{D_{1,m}\}$ is much higher than that for $\{B_{m,k}\}$ to suit a fast fading environment.

**Figure 6** shows a block diagram of the base station with two sub-arrays, each of which has two elements ($N$ = 4, $M$ = 2). We simulated the required transmission power versus the velocity of a mobile station for when our proposed multiple antenna transmit diversity scheme is implemented using this sub-array antenna configuration. **Figure 7** shows the results together with the results for a single antenna transmission, a 2-antenna and 4-antenna transmit diversity using Mode-1,[10] and the 2 × 2 sub-array using Mode-1. The following conclusions can be drawn from Figure 7.

- Simple extension of transmit diversity Mode-1 rapidly degrades the performance in the high-mobility region due to the limited feedback bandwidth.
- The proposed scheme improves the performance regardless of the mobility.
- The proposed scheme can reduce the average transmitter Ec/Ior by about 1.8 to 2.0 dB below the 2-antenna, Mode-1 levels.

## 5. Conclusion

We have presented several new techniques for realizing efficient IP data transmission over the cellular networks of IMT-2000 and beyond. We analyzed the functional requirements in the data link layer for transmission of heterogeneous IP traffic with different QoS requirements. For the radio access technologies, we proposed two novel

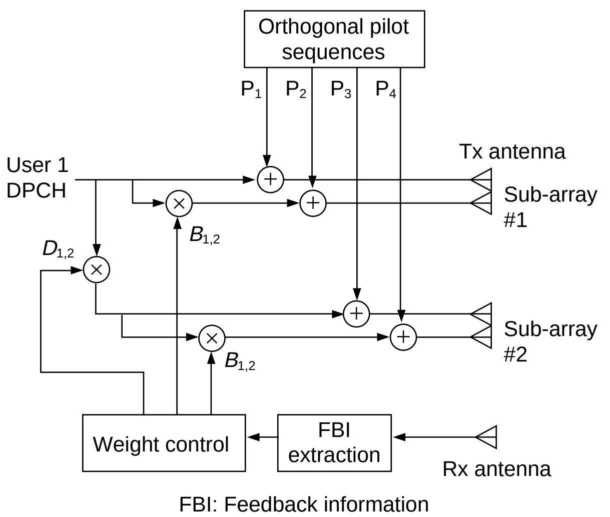


Figure 6
Block diagram of combined Tx diversity/beam forming ($N$=4, $M$=2).

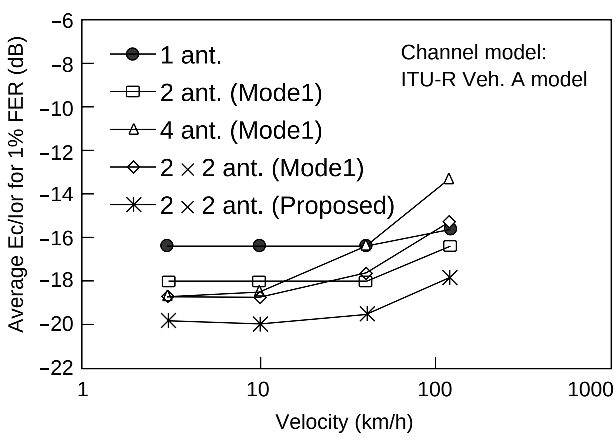


Figure 7
Required transmission power vs. velocity.

spatial processing techniques for efficient packet transmission. One is an advanced path searcher with a direction-of-arrival estimation capability for IMT-2000 base stations which employ an adaptive array antenna. The other is a closed-loop transmit diversity technique with a beam-forming capability. We explained that both techniques can improve system capacity and reduce the required transmission power.

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