

cdma2000 1x Rev. E Forward Link Voice Capacity

Yucheun Jou, Peter Black, Qiang Wu, Rashid Attar, Wanlun Zhao, Bharat Ahuja, Junsheng Han
Qualcomm Inc, San Diego, CA 92121, USA

Abstract—The forward link capacity of a cdma2000 1x system is power limited. Therefore, average data rate (ADR), link efficiency, and receiver signal-to-noise ratio (SNR) are the key factors for capacity improvement. In this paper, we introduce the new features of the Forward Fundamental Channel (F-FCH) with Radio Configuration (RC) 11 for 1x Revision E that is being standardized at the Third Generation Partnership Project 2 (3GPP2)¹ and advanced receivers for mobile stations (MS), targeted at these key factors. Simulations show that the new RC together with interference cancellation and a new voice codec more than doubles the forward link capacity of existing 1x systems, and more than triples the capacity with dual receive antennas. The capacity gain is achieved without any increase in voice latency or any degradation in voice quality.

Index Terms—cdma2000, 1x, Revision E, Forward link voice capacity, Frame early termination, DTX, EVRC, EVRC-B, Interference cancellation, Receive diversity.

I. INTRODUCTION

A cdma2000 1x base station (BS) can use Walsh functions and quasi-orthogonal functions (QOFs) to spread code channels [1] [2]. There are three sets of QOFs defined in 1x, quadrupling the code capacity of IS-95. As a result, the forward link capacity of a typical 1x system cannot be code limited. Rather, it is power limited.

The key factors for improving the power-limited forward link are ADR, link efficiency, and receiver SNR. In this paper, we introduce the new features of the F-FCH with RC 11 and advanced receiver techniques, targeted at these key factors. The former includes discontinuous transmission (DTX) support, frame early termination (FET), and reduced power control overhead; and the later includes interference cancellation and receive diversity.

We compare two codec's in this paper, EVRC and EVRC-B, developed at 3GPP2 [3]. EVRC compresses the voice source into three types of 20 ms codec frames: full rate, $\frac{1}{2}$ rate, and $\frac{1}{8}$ rate. EVRC-B is a new generation of codec. One significant difference in EVRC-B is the use of a new $\frac{1}{4}$ -rate codec frame that is not used in EVRC. EVRC-B can provide lower ADR than EVRC for a given voice quality.

The remainder of this paper is organized as follows. In section II, we briefly review the background knowledge on cdma2000 1x forward link. In section III, we introduce the new features of the F-FCH with RC 11. In section IV, we discussed advanced receiver techniques at MS. In section V, we show simulation results about the improved forward link voice capacity. Finally, we conclude the paper in section VI.

¹The cdma2000 1x standard Revision E is scheduled for publication in the second quarter of 2009 and will be available at <http://www.3gpp2.org>.

II. BACKGROUND

In this section, we review some basic aspects of cdma2000 1x [1] [4], in order to set up the discussion in this paper.

A cdma2000 forward link carrier is allocated 1.25MHz of bandwidth. The forward link signal is spread by a pseudo-noise (PN) sequence at the rate of 1.2288Mcps with a sector-specific offset, known as the PN offset. The offset PN sequence rolls over every 32768 chips (26.66...ms) and aligns with the CDMA system time.

In the forward link, channels are code division multiplexed by Walsh functions and QOFs. There are three types of overhead channels transmitted by each sector: Pilot, Sync, and Paging. The Pilot channel carries the unmodulated symbols, which serve as the reference signal for acquisition, demodulation, handoff, and set management, etc. The Sync channel carries the system information that the MS needs to identify the PN offsets being acquired through pilot. The Paging channel carries more detailed system information and mobile-specific messages. The Pilot channel, the Sync channel, and the mandatory primary Paging channel use Walsh functions W_0^{64} , W_{32}^{64} , and W_1^{64} , respectively.

The F-FCH is a dedicated traffic channel. RC 3 and 4 allow four types of 20 ms physical layer frames on the F-FCH at data rates 9600, 4800, 2700 and 1500 bps. These are also called full rate, half rate, quarter rate, and eighth rate (physical layer) frames, corresponding to the four types of codec frames they carry, respectively. A 20 ms frame is composed of 16 power control groups (PCG), each 1.25 ms long. The F-FCH with RC 3 uses a rate- $\frac{1}{4}$ code, spreading length of 64, and QPSK modulation; while the F-FCH with RC 4 uses a rate- $\frac{1}{2}$ code, spreading length of 128, and QPSK modulation. An F-FCH is assigned to an active MS by each sector in the MS's active set, and is power controlled at typically 800 Hz so that the minimal transmit power is used to achieve a desired E_b/N_0 target. All F-FCHs assigned to one MS carry the same information.

A RAKE receiver at the MS assigns fingers to the strongest paths from the active sectors, and then combines these fingers coherently before demodulating the F-FCH.

III. F-FCH WITH RC 11

In this section, we discuss the F-FCH of RC 11 [5], which is designed based on the framework of RC 4 but with three key enhancements. The purpose of these enhancements is to reduce ADR and improve link efficiency.

A. DTX Support

A new service option of EVRC-B with DTX is being standardized for cdma2000 1x. When DTX is enabled, the

codec can produce zero-rate codec frames during the silence period. The F-FCH with RC 11 adds a new 0 bps frame type for the zero-rate codec frames. As a result, the F-FCH with RC 11 provides DTX support for the new service option.

Long runs of 0 bps frames may halt the power control outer loop. So when operating with RC 11, the F-FCH transmits at least one non-zero rate frame every F-FCH_N frames, which can be the Null Traffic Channel Data.

B. FET

The F-FCH with RC 3 and 4 transmits four types of 20 ms frames. With the forward power control, 99% of the frames can be decoded successfully. Interestingly, most of the frames can be decoded successfully before the entire frame is received. Fig. 1 shows the early decoding statistics for the F-FCH of RC 4 under the 1x mixed channel condition (see table II of section V) over all users in a simulated network. We observe that, for example, around 80% of the eighth rate frames can be decoded successfully after the first 7 PCG's are received. In other words, for 80% of the eighth rate frames, transmissions beyond the first 7 PCG's are redundant and can only result in lower link efficiency.

For the F-FCH of RC 11, MS attempts to decode each frame prior to the end of the nominal duration (20 ms) of the frame. Once the MS successfully decodes the frame, it transmits an ACK to the BS's. If the BS receives an ACK it shall stop transmitting the F-FCH for the remainder of the frame duration. An ACK mask indicates the PCG's during which the BS may receive an ACK. FET defined here does not increase the air-link latency because it does not use an interlaced frame structure.

Fig. 2 shows an example timeline of FET. The ACK mask of '0000000110011000' indicates that the BS may receive an ACK only in PCG 7, 8, 11, or 12. The MS attempts to decode after PCG 6 and 7, and is able to decode it successfully after PCG 7; then it sends an ACK back in PCG 8. The BS receives the ACK in PCG 8 and stops transmission on the F-FCH for the remainder of the frame.

In order to reduce the probability of false CRC passes in the early decoding attempts for the F-FCH with RC 11, 12-bit CRC is used for all the non-zero rate frames. As a result, the F-FCH with RC 11 has five data rates at 9600, 5000, 3000, 1800, and 0 bps.

C. Reduced Power Control Overhead

The forward power control subchannel (F-PCSCH) for the reverse power control is transmitted on the F-FCH. Typically, the F-PCSCH transmits one power control bit (PCB) per PCG, i.e., at 800 bps. The transmit power of the F-PCSCH is typically the same as that of the F-FCH during a 9600 bps frame, and does not scale down for lower frame rates. To ensure reliable reception during soft handoff, the transmit power of the F-PCSCH is further scaled by the number of cells in the active set. Fig. 3 shows the transmit power profile for the F-PCSCH. If we assume two cells in the active set and the EVRC-B codec, then the F-PCSCH consumes 34% of

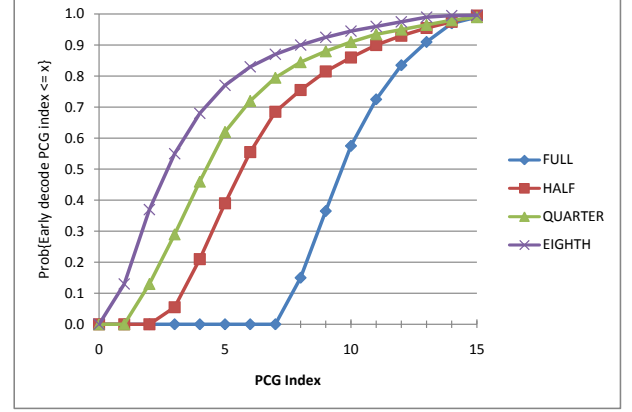


Fig. 1. Early decoding statistics of F-FCH with RC 4

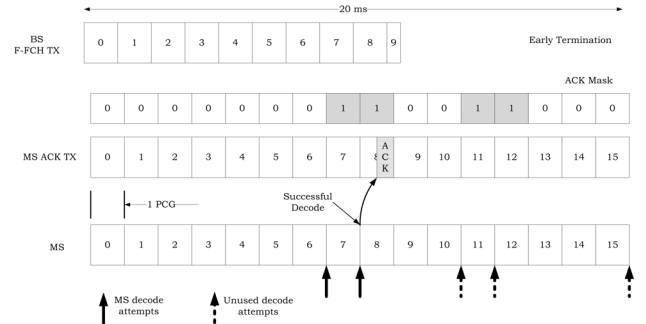


Fig. 2. Example of Frame Early Termination

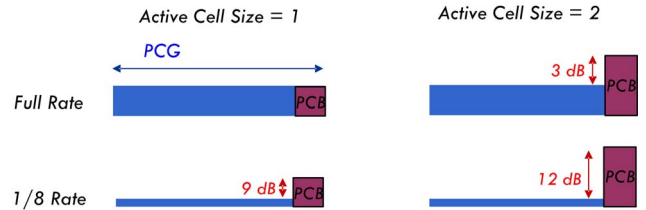


Fig. 3. Transmit power profile of F-PCSCH

the total power for the F-FCH. The power control overhead is significant.

Given FET introduced for the F-FCH with RC 11, a slower forward power control is sufficient for link efficiency. The slower forward power control reduces the overhead of the reverse power control subchannel (R-PCSCH) with RC 8 (the new reverse link RC for 1x Revision E). Since a similar (virtual) ARQ mechanism can be implemented for the R-FCH [6], a slower reverse power control is then sufficient, which reduces the overhead of F-PCSCH with RC 11.

Fig. 4 and 5 show the forward and reverse power control timing (RC 11 on forward link and RC 8 on reverse link) if POWER_CONTROL_MODE = '00'. When DTX support for

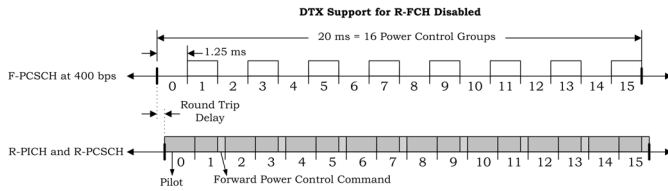


Fig. 4. Power Control Timing for $\text{POWER_CONTROL_MODE} = '00'$: DTX Support for the R-FCH Disabled

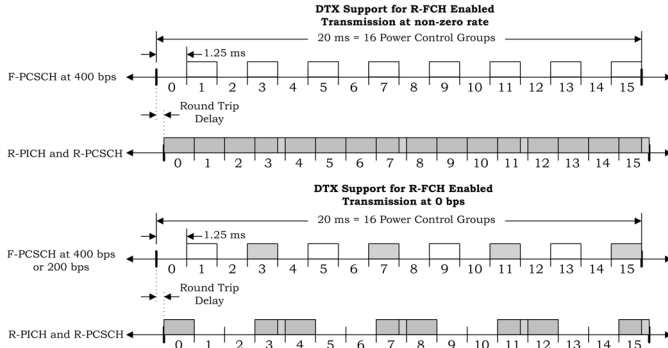


Fig. 5. Power Control Timing for $\text{POWER_CONTROL_MODE} = '00'$: DTX Support for the R-FCH Enabled

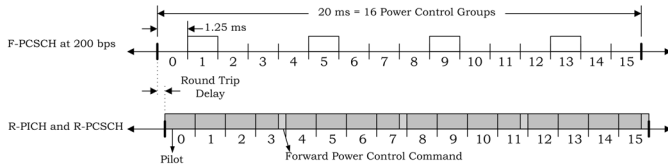


Fig. 6. Power Control Timing for $\text{POWER_CONTROL_MODE} = '01'$

the R-FCH is disabled, the F-PCSCH transmits one bit every two PCG's (in the odd PCG's) at 400 bps. The forward power control performs SNR measurement on the F-PCSCH. Then the forward power control commands are transmitted on the R-PCSCH also at 400 bps. When DTX support for the R-FCH is enabled, the F-PCSCH transmits at either 400 or 200 bps, while the R-PCSCH transmits at 200 bps.

Fig. 6 shows the forward and reverse power control timing (RC 11 on forward link and RC 8 on reverse link) if $\text{POWER_CONTROL_MODE} = '01'$. Regardless of DTX support for the R-FCH, both the F-PCSCH and R-PCSCH transmit at 200 bps.

IV. ADVANCED RECEIVER TECHNIQUES

In this section, we discuss the advanced receiver techniques that greatly improve the receiver SNR.

The conventional RAKE receiver is shown in Fig. 7. Each branch in the figure is referred to as a finger. There are L fingers assigned to the paths from the active sectors. $t_0, \dots, t_{L-1}$ are the delays of these paths. Despread operation refers to correlating with the combined PN and orthogonal spreading sequence. $w_0, \dots, w_{L-1}$ are the combining weights. If $w_l = h_l^*$, where h_l is the fading coefficient of the l -th path, the receiver is called pilot weighted combining RAKE

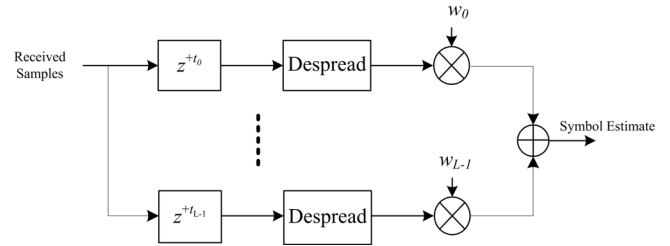


Fig. 7. RAKE Receiver

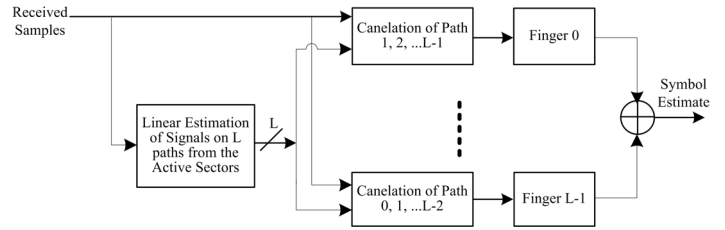


Fig. 8. Linear Interference Cancellation Receiver

(PWC-RAKE). In the rest of this section, we explore advanced receiver techniques on interference cancellation and receiver diversity.

A. Interference Cancellation

Fig. 8 shows a possible structure for the linear interference cancellation receiver. The core component is the linear estimation block for the L paths from the active sectors. The estimates of path $1, \dots, L-1$ are cancelled from the received signal such that a cleaner signal with reduced interference is presented to the finger processing for path 0. The similar cancellation procedure is applied to other fingers.

This structure can be generalized in multiple ways. One generalization is for neighbor set interference cancellation. Note that, linear estimates can be obtained for the paths from the neighboring sectors as well. Although these paths do not directly contribute to signal combining, but they can still contribute to interference cancellation by removing them from the received samples.

Another generalization of this structure is for QOF interference cancellation. Fig. 8 assumes that only Walsh functions are used for each sector. If QOFs are used, linear estimate can be obtained separately for the signal from each orthogonal set on the L paths. As a result, not only the interference from all orthogonal sets on the other paths but also the interference from the other orthogonal sets on the same path can be cancelled.

B. Receive Diversity

The receive diversity technique provides both power and diversity gains for the receiver SNR, and thus is effective for voice capacity enhancement. The interference cancellation receiver shown in Fig. 8 can be generalized for multiple receive antennas, the structure of which is shown in Fig. 9. The linear estimation block generates estimates for the L paths

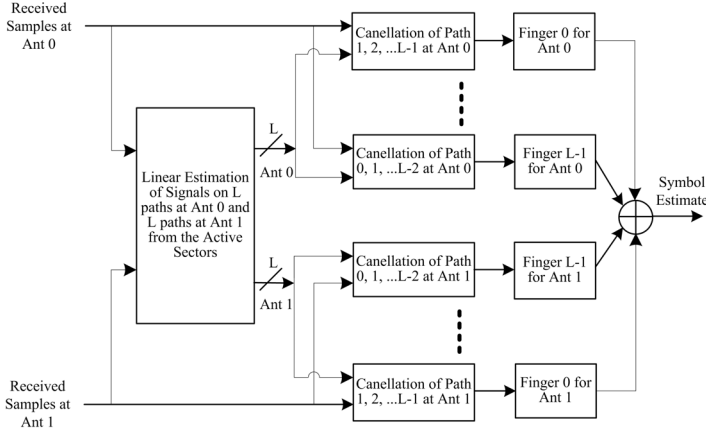


Fig. 9. Linear Interference Cancellation with Dual Receive Antennas

at both antenna 0 and the antenna 1 from the active sectors. Note that, multi-paths and multi-antennas from a sector carry the same signal scaled by different fading coefficients, so joint processing is preferred in generating the estimates. Cancellation is done for each antenna separately. Finally, fingers are combined over paths and antennas.

V. SIMULATIONS

In this section, we review the simulation assumptions for the network simulator developed based on the 3GPP2 evaluation methodology [7], and then show the voice capacity results.

A. Simulation Assumptions

The key assumptions for the network simulations of a cdma2000 1x system are summarized in table I. Table II shows the cdma2000 1x channel mix. Fig. 10 shows the rate distributions for EVRC and EVRC-B.

TABLE I
NETWORK SIMULATION ASSUMPTIONS

Network layout	19 cells (57 sectors) with wraparound
Site-to-site distance	2 km
Maximum allowable path loss	138 dB
Channel model	1x channel mix (table II)
Spatial correlation of dual antennas	0.5
Imbalance of dual antennas	4 dB
T_{add}	corresponds to the average active set size of 1.7
Maximum transmit power	20 Watts
Power for Pilot, Sync and Paging	4 Watts
Min power for F-FCH at 9600 bps	0.02 Watts
Max power for F-FCH at 9600 bps	1.7825 Watts
Power for F-PCSCH	power for F-FCH at 9600 bps $\times$ num cells in active set
Rate of F-PCSCH	400 or 200 bps
FET excessive transmission	1 PCG after ACK is received
FET ACK delay	ACK sent in PCG n if decoding attempt for PCG n-1 succeed for every PCG
FET decoding attempts	10%
FET ACK miss rate	200 bps
Rate of R-PCSCH	based on SNR estimate
Generation of PCB on R-PCSCH	4%
Error rate of PCB on R-PCSCH	3 dB
Min outer loop set point in Eb/No	8 dB
Max outer loop set point in Eb/No	4 frames
F-FCH_N	

Sectors assign QOFs when needed. Two types of receivers at MS are considered: PWC-RAKE and QLIC. QLIC (Qualcomm Linear Interference Cancellation) is a patented technology that follows the structure in Fig. 8. If QOFs are assigned, QLIC is generalized for QOF interference cancellation. If dual antennas are used, QLIC is generalized to the diversity

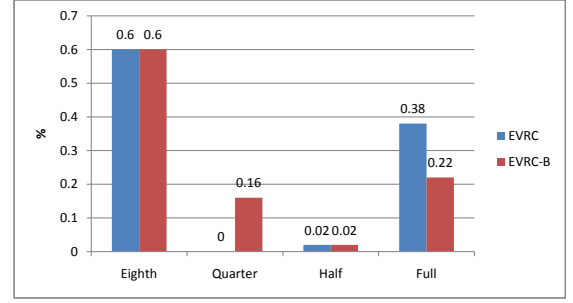


Fig. 10. EVRC and EVRC-B Rate Distribution

structure. In this section, we do not consider the generalization for neighbor set interference cancellation.

B. Voice Capacity

Capacity can be defined in two ways as the maximum number of users/sector/1.25 MHz such that

- the average sector transmit power ≤ 14 Watts, or
- $\leq 5\%$ of the users are in outage (average FER $\geq 2\%$)

Fig. 11 shows the sector power and percentage of users in outage for EVRC, RC 3, one antenna, and RAKE. In this case, the capacities are 28 and 30 for the power and outage based definitions, respectively. Simulations show that in general the two capacities are very close, often the former being slightly conservative. As a result, the definition based on sector power is adopted in this paper.

Table III and IV show the voice capacities for full loading and extreme partial loading, respectively. In the full loading condition, all sectors in the network are equally loaded with users. In the extreme partial loading condition, we only care about the capacity in the central cell which is loaded with users; the rest of the sectors in the network are unloaded with users in the sense that other than transmitting the Pilot, Sync and Paging channels they transmit F-FCH only when it is needed to support soft handoff for the users in the central cell. Practical systems are often partially loaded, i.e., lightly loaded cells surround a heavily loaded cell, the capacity of which would be somewhere between the numbers shown in table III and IV.

TABLE II
1X CHANNEL MIX

Channel Type	Delay Profile	Speed	K factor	Percentage
Channel B	3 paths	10 km/hr	0	30%
Channel C	2 paths	30 km/hr	0	20%
Channel D	1 path	120 km/hr	0	10%
Channel E	1 path	0.81 km/hr	10	40%

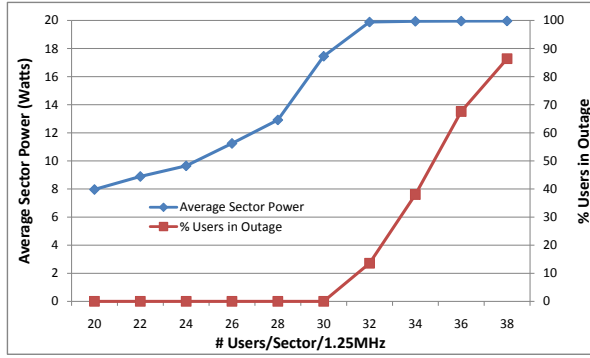


Fig. 11. Definitions of Capacity: Power vs Outage

The capacity can change as the simulation assumptions change. Therefore, we should pay more attention to the relative enhancement in capacity. The better capacity of RC 3 and RC 4 for EVRC and one-antenna RAKE is considered as the baseline capacity of the existing 1x systems. Table III and IV show that the baseline capacities for full loading and extreme partial loading are 28 and 75, respectively. Note that, the active set size is tuned to 1.7 in the simulations, which means the Walsh code limited capacities are 35 and 71 for RC 3 and RC 4, respectively. In the full loading condition, both RC 3 and RC 4 have capacities below Walsh limitations, so RC 3 wins due to the stronger code thus better link efficiency. In the extreme partial loading condition, both RC 3 and RC 4 have capacities above Walsh limitations, so RC 4 wins due to the less usage of QOFs. Table V and VI show capacity enhancement relative to the baseline. We observe that EVRC-B, RC 11 and QLIC more than doubles the forward link capacity with one antenna, and more than triples the capacity with dual antennas.

One might have the desire to itemize the gain of each enhancement feature, and then easily derive the gains of different subsets of features. However, it does not make sense when these features are interactive. For example, EVRC-

TABLE III
FORWARD LINK VOICE CAPACITY FOR FULL LOADING

#users/sect/1.25MHz	EVRC, RC 3	EVRC, RC 4	EVRC-B, RC11	
			F-PCSCH 400 bps	F-PCSCH 200 bps
1-ant RAKE	28	26	66	74
1-ant QLIC	33	33	79	88
2-ant QLIC	41	48	99	114

TABLE IV
FORWARD LINK VOICE CAPACITY FOR EXTREME PARTIAL LOADING

#users/sect/1.25MHz	EVRC, RC 3	EVRC, RC 4	EVRC-B, RC11	
			F-PCSCH 400 bps	F-PCSCH 200 bps
1-ant RAKE	66	75	142	155
1-ant QLIC	86	99	193	220
2-ant QLIC	101	125	240	273

B improves capacity by having a lower ADR due to the use of quarter-rate frames. The use of quarter-rate frames instead of full-rate frames means the power control overhead is more significant, thus a slower power control becomes more effective in overhead reduction. The use of quarter-rate frames also indicates more FET gains because quarter-rate frames are more likely to be decoded successfully in early PCG's than full-rate frames. Therefore, it is impossible to quantify the gain of EVRC-B alone when it is used with other enhancements. We should consider the group of enhancement features altogether.

VI. CONCLUSION

In this paper, we discussed power limitation on the forward link voice capacity of cdma2000 1x systems, and pointed out the key areas of improvement, namely, ADR, link efficiency, and receiver SNR. We first introduced the key new features of F-FCH with RC 11: DTX support, FET, and reduced power control overhead. The purpose of these enhancements is to reduce ADR and improve link efficiency. Then, we discussed advanced receiver techniques including interference cancellation and receiver diversity, the purpose of which is to improve receiver SNR. Finally, we showed the simulation results following the 3GPP2 evaluation methodology. We conclude that the new RC with interference cancellation and EVRC-B codec more than doubles the forward link capacity of the existing 1x systems, and more than triples the forward link capacity if dual receive antennas are used.

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TABLE V
FORWARD LINK VOICE CAPACITY GAINS FOR FULL LOADING

#users/sect/1.25MHz	EVRC, RC 3	EVRC-B, RC11	
		F-PCSCH 400 bps	F-PCSCH 200 bps
1-ant, RAKE	1	2.36	2.64
1-ant, QLIC	1.18	2.82	3.14
2-ant, QLIC	1.46	3.54	4.07

TABLE VI
FORWARD LINK VOICE CAPACITY GAINS FOR EXTREME PARTIAL LOADING

#users/sect/1.25MHz	EVRC, RC 3	EVRC-B, RC11	
		F-PCSCH 400 bps	F-PCSCH 200 bps
1-ant RAKE	1	1.89	2.07
1-ant QLIC	1.32	2.57	2.93
2-ant QLIC	1.67	3.20	3.64