

# Advanced receivers for WCDMA terminal platforms and base stations

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WCDMA continues to evolve to support high-bit-rate applications. High-speed downlink packet access (HSDPA) technology, for example, substantially increases data rates in the downlink. As data rates increase, however, greater self-interference from the dispersive radio channel limits performance. As a consequence, Ericsson has developed advanced receivers for WCDMA terminal platforms and base stations.

The authors describe an advanced receiver approach known as generalized Rake (G-Rake) reception. The G-Rake receiver functions like an equalizer, suppressing self-interference. To minimize cost and time-to-market, the receiver architecture builds on the traditional Rake receiver architecture. Tests show that the G-Rake receiver can significantly improve throughput and system capacity for high-bit-rate applications. Ericsson will include G-Rake for HSDPA services starting with its U350 and U360 WCDMA platforms.

G-Rake reception is also being considered for other applications. For voice service, for instance, it can increase downlink capacity by 30%. Data and voice applications improve when G-Rake reception is used in conjunction with the two-antenna terminal platforms that are part of EMP's technology roadmap. G-Rake will also significantly improve performance on the uplink when data rates exceed 2Mbps in later phases of the enhanced uplink (EUL).

## Background

WCDMA technology is being deployed worldwide to provide third-generation mobile systems and services. The WCDMA standard continues to evolve with HSDPA and EUL.<sup>1-2</sup>

Receiver technology is also evolving. Today's terminals and base stations employ Rake receivers, which collect signal energy that has been dispersed in time by the multi-

path radio channel. In the future, however, besides collecting signal energy, advanced receivers will be used to suppress interference. In this regard, G-Rake receivers show great promise.<sup>3</sup>

To understand the G-Rake receiver, let us briefly review WCDMA transmission. Figure 1 shows the transmission and reception of a single stream of information. Information bits are encoded with a forward error correction (FEC) encoder, such as a convo-

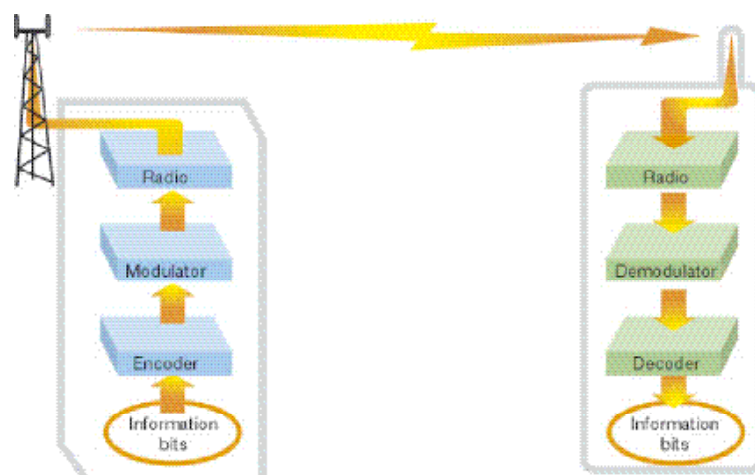
lutional encoder or turbo encoder. The encoded bits are used to create modulation symbols, such as quadrature phase-shift keying (QPSK) symbols. These are then spread so that each symbol is represented by a sequence of "chips." Next, the spread-spectrum signal is mixed up to a radio frequency and transmitted. At the receiver, the radio signal is mixed down to baseband for demodulation and decoding.

## G-Rake reception

The G-Rake receiver, which resides in the demodulator, produces estimates of the modulation symbols from the received signal. Because the G-Rake receiver is similar to a traditional Rake receiver, let us also briefly review Rake reception.

Signal energy is collected from different delayed versions of a transmitted signal. As seen in Figure 2, the channel response creates multiple images of the transmitted signal (that is, the dispersive, multipath channel gives rise to different versions). The "fingers" of the Rake receiver extract signal energy from delayed signal images by despreading and combining them – the Rake receiver coherently combines the finger outputs using complex conjugates of estimated channel coefficients to estimate the modulation symbol. Figure 3 shows a simple example in which two despread values are combined ( $x_1$  and  $x_2$ , which correspond to two signal paths). Each despread value consists of a signal component ( $s$ ), an interference component ( $i$ ), and a noise component ( $n$ ). When combining the values, the Rake

Figure 1  
WCDMA communication link.



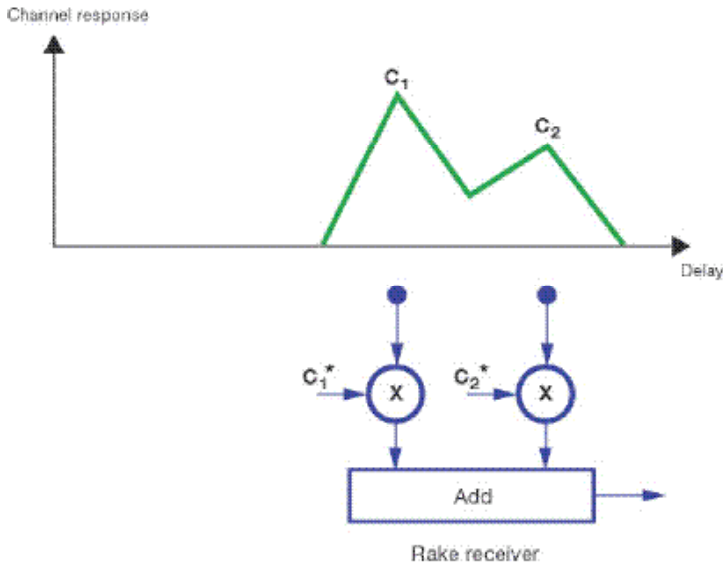


Figure 2  
Rake receiver.

receiver aligns the signal components so that they add to one another, creating a larger signal component.

Figure 4 shows a G-Rake receiver. Like the Rake receiver, it uses fingers and combining techniques to estimate a symbol. However, there are two important differences:

- Extra “interference” fingers are used to collect information about interference on the “signal” fingers. This interference might result from other symbols of interest (self-interference), symbols intended for other users in the cell (own-cell interference), or symbols intended for other users in other cells (other-cell interference). The extra fingers capture information about the interference. This is used to cancel interference on the “signal” fingers. To work well, the interference must pass through a dispersive channel.
- A separate method is used to form *combining weights*. Rake receivers use a weighted sum of despread values to estimate symbols. For example,

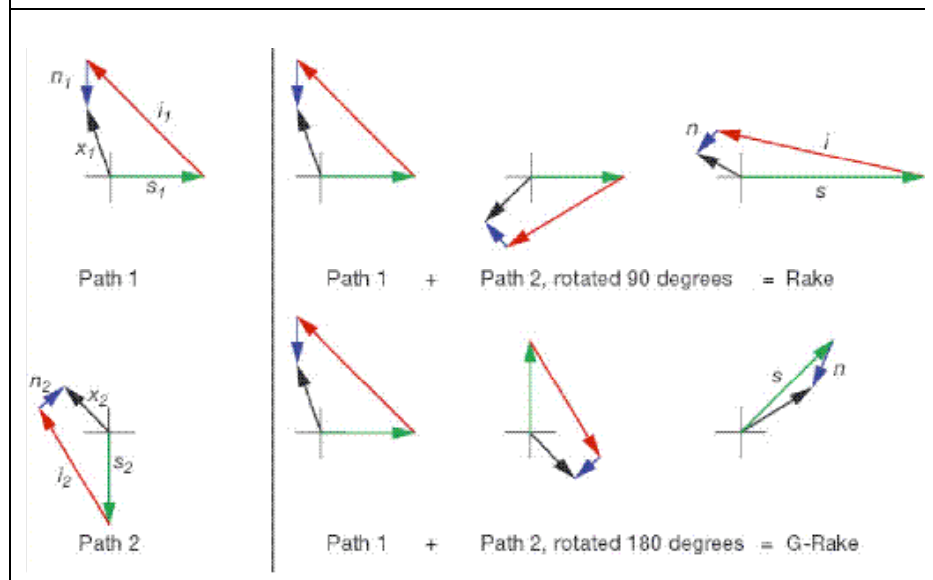
$$y = \mathbf{w}^H \mathbf{x} = w_1^* x_1 + w_2^* x_2$$

where  $\mathbf{x}$  represents the despread values and  $\mathbf{w}$  represents the combining weights. The multipliers (which multiply the despread values) are called combining weights. Despread values are thus combined using combining

weights. Besides estimating the channel, the G-Rake receiver estimates the correlation between the impairment (interference plus noise) on different fingers. The correlation captures the “color” of the impairment. This information can be used to suppress interference. Channel estimates and impairment correlation estimates are used to form the combining

weights. As a result, the combining process collects signal energy and suppresses interference. The G-Rake receiver (Figure 3) combines the two despread values to cancel interference and increase the signal component. By contrast, the Rake receiver solely maximizes the signal component. It does nothing about the interference component.

Figure 3  
Rake and G-Rake receiver examples.



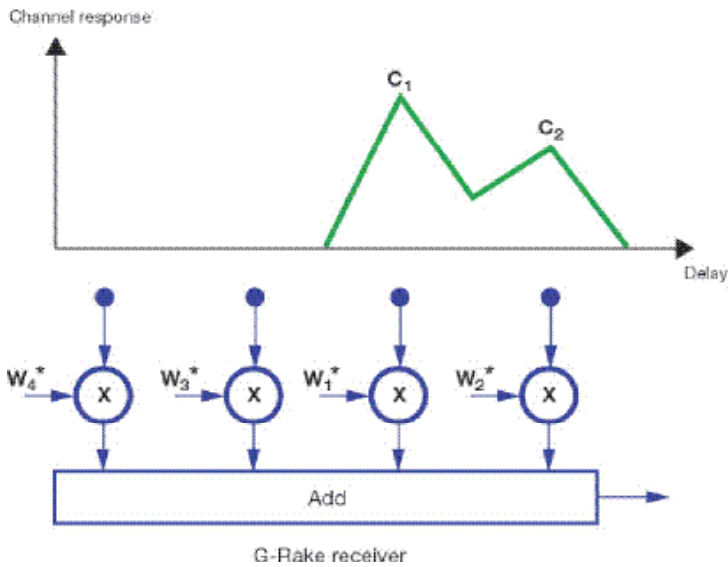


Figure 4  
G-Rake receiver.

The combining weights are optimized for performance, maximizing the signal-to-impairment ratio ( $S/I$ ). They thus trade off the need to collect signal energy (maximizing  $S$ ) with the need to suppress interference (minimizing  $I$ ). Using linear algebra, we can express the vector of combining weights as

$$\mathbf{w} = \mathbf{R}^{-1}\mathbf{c},$$

where  $\mathbf{c}$  is a vector of estimated channel coefficients (padded with zeros for the inter-

ference fingers) and  $\mathbf{R}$  is a matrix of estimated impairment correlations. The combining weights for Rake reception are merely the estimated channel coefficients:

$$\mathbf{w} = \mathbf{c}.$$

Note therefore that Rake combining is a special case of G-Rake combining in which  $\mathbf{R}$  is set to an identity matrix. When there is no interference to suppress, G-Rake is equivalent to Rake reception.

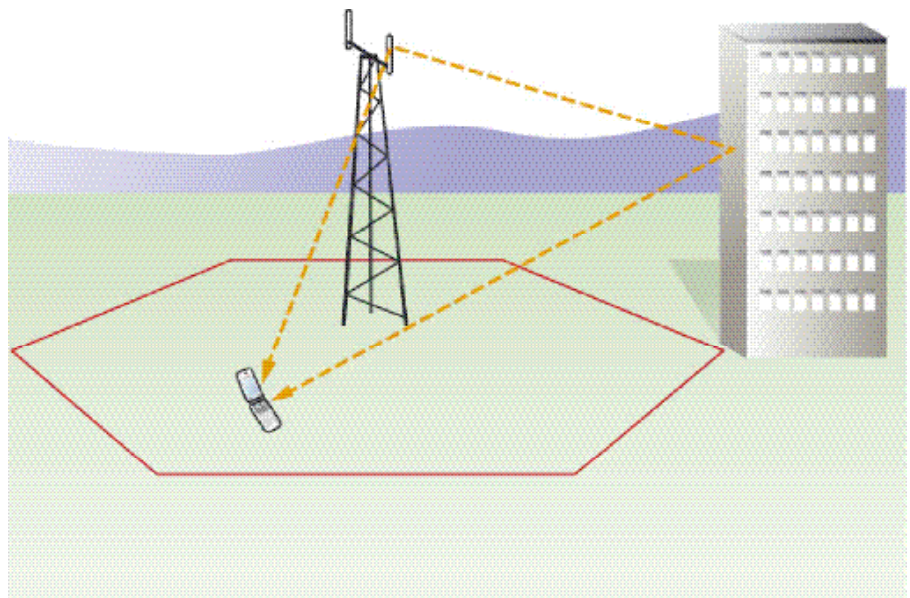
## Downlink

In a WCDMA downlink, a base station transmits to multiple users using parallel streams of information spread on different spreading codes. Interference between streams is minimized by means of orthogonal spreading codes. However, these codes are only orthogonal when aligned in time. When the channel is dispersive, orthogonality is lost, because one image of the base station signal at one delay is not orthogonal to another image at another delay.

Figure 5 shows an example of downlink transmission relative to a particular user. In this example, there are two signal images, the second being caused by a reflection from a building. The finger assigned to the first signal image sees interference from the second signal image and vice versa. Extra fingers see interference from both. The G-Rake receiver functions like a linear equalizer, inverting the channel to restore orthogonality and suppress own-cell interference. Like a minimum mean-square error (MMSE) linear equalizer, it strikes a balance between restoring orthogonality and suppressing noise and other-cell interference.

The introduction of G-Rake reception can significantly improve performance because it helps suppress own-cell interference, which can be considerable when the channel is dispersive. The more orthogonality the G-Rake receiver restores, the more it suppresses own-cell interference.

Figure 5  
WCDMA downlink example.



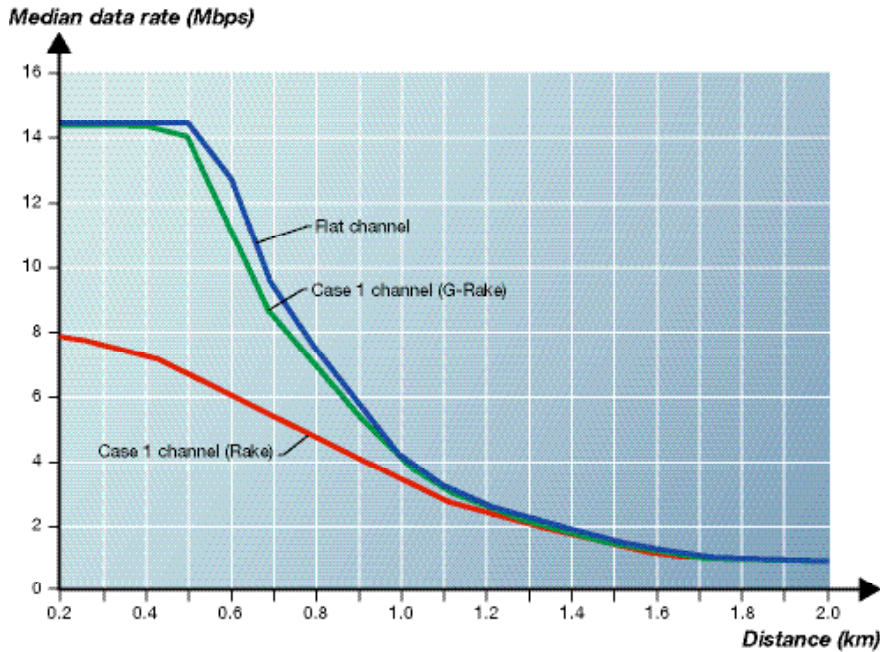


Figure 6  
Median data rate versus distance from the base station. (Flat = one signal path, Case 1 test channel = two signal paths with average power of 0 and -10dB.)

Figure 6 shows the median data bit rate provided by HSDPA as a function of distance from the base station. Two channel conditions are considered: a flat fading channel and a mildly dispersive channel.

With a flat fading channel (one signal image) G-Rake and Rake reception are equivalent. The median bit data rate falls as distance increases, because signal power weakens. The bit rate is flat over short distances.

Figure 6 also shows the results when the channel is mildly dispersive (Case 1, WCDMA test channel, two signal images, one 10dB weaker than the other). Note that the results for Rake and G-Rake reception differ considerably. With G-Rake reception, the median bit rate is almost as good as that of the flat channel (no interference). However, with Rake reception, the median bit rate is much lower, due to interference, when the receiver is close to the base station. G-Rake reception thus significantly improves coverage for high data bit rates. From Figure 6, we can also see that G-Rake techniques approximately double the coverage area when data rates are around 6Mbps (see also Table 1).

At great distances, the data rates decrease and the G-Rake and Rake curves merge. This is because signal power diminishes with distance and performance is limited by

other-cell interference (as opposed to self- and own-cell interference).

Where HSDPA is concerned, G-Rake reception improves link performance, which translates into a 30% to 35% gain in system capacity.<sup>4</sup> For voice, G-Rake reception improves capacity by 30% to 34%.<sup>5</sup> Note also that G-Rake reception fulfills 3GPP requirements for type-2 receivers.<sup>6</sup>

Ericsson has implemented G-Rake reception in the laboratory and as part of an HSDPA testbed.<sup>2,7</sup> Figure 7 describes the testbed performance. The data bit rate is shown as a function of  $I_{or}/I_{oc}$  (dB), or the ratio of received base station power to other-cell interference. The channel, *Vehicular A*, is highly dispersive, causing significant self-interference, which limits the data bit rate. From these results we see that G-Rake reception has the potential to increase the data bit rate 50% to 100% regardless of vehicle speed.

## Multiple receive antennas

With multiple receive antennas, fingers are placed on each antenna signal. The combining weights are determined jointly for the overall set of fingers. In this case, elements in the **R** matrix include impairment correlations between fingers assigned to different receive antennas. The use of impair-

### BOX A, TERMS AND ABBREVIATIONS

EMP	Ericsson Mobile Platforms
EUL	Enhanced uplink
FEC	Forward error correction
G-Rake	Generalized Rake
HSDPA	High-speed downlink packet access
MMSE	Minimum mean-squared error
QPSK	Quadrature phase-shift keying
S/I	Signal-to-interference ratio
WCDMA	Wideband code-division multiple access

TABLE 1. SYSTEM SIMULATION SETUP FOR DATA RATE VERSUS DISTANCE

Parameter	Setting
Path loss exponent	4
Log-normal shadowing deviation	8dB
Receiver noise figure	8dB
Transmit power	20W
Temperature for noise level setting	290K
Site-to-site separation	3km
Site layout	Hexagonal, 19 sites
Antenna pattern	Unity gain in 120-degree sector

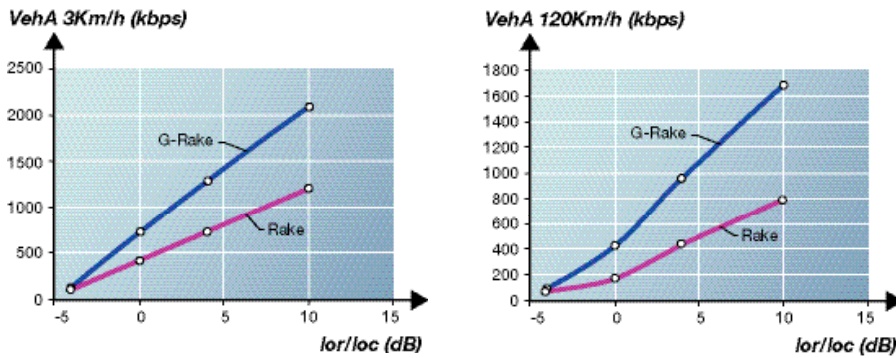


Figure 7  
 Left: Testbed performance, FTP file transfer, Vehicular A channel, 3 km/h.  
 Right: Testbed performance, FTP file transfer, Vehicular A channel, 120 km/h.

ment correlations to compute combining weights yields a form of adaptive array processing or beamforming.

Consider a two-antenna receiver that sees a single signal image from one direction and a single interfering signal image from another direction. It uses two fingers, one per antenna, aligned with the desired signal image. The two-antenna G-Rake receiver (G-Rake2) functions like an adaptive beamformer, giving large gain in the direction of the desired signal and steering a null (low gain) in the direction of the interferer. In the downlink example of Figure 5, a G-Rake2 receiver would form two beams: one to each signal image.

In the more general case, scattering creates many signal and interference images. G-Rake2 thus tries to make signal images add and interfering images cancel. This is a trade-off, intended to maximize S/I.

With traditional Rake reception, a second, low-cost receive antenna (low gain, fading

correlated with other antenna) would not be very beneficial. However, with G-Rake2, a second antenna could help suppress interference. Performance is dependent on the peak data rate supported by the system. As higher bit rates become available via HSDPA, the introduction of a G-Rake2 receiver will significantly improve performance.

## EMP product plans

Ericsson Mobile Platforms (EMP) plans to incorporate G-Rake reception into its products. G-Rake reception for HSDPA services will be available in products built on the U350 and U360 platforms. These platforms have been planned to facilitate true mass-market HSDPA volumes by enabling mid-tier WCDMA/HSDPA designs with strong emphasis on total size, cost, and performance. The U350 is a quad-band EDGE and single-band WCDMA platform; the U360 is a quad-band EDGE and triple-band

WCDMA platform for any combination of two high and one low 3GPP WCDMA bands. G-Rake2 is also part of the EMP technology roadmap.

## Uplink

In the WCDMA uplink, multiple users transmit information in parallel using non-orthogonal codes. Recently, the uplink has evolved to support even higher data rates (with EUL). As in the downlink, a high-bit-rate user transmits multiple streams in parallel using orthogonal codes. Low spreading factor is also used. When the channel is dispersive, self-interference occurs. G-Rake reception provides a form of equalization, enabling high-bit-rate coverage in dispersive channels. However, because much of the own-cell interference is from other, non-orthogonal users, the gains in the uplink from G-Rake reception are not very significant until data bit rates exceed 2Mbps.

## Conclusion

As WCDMA evolves to higher-bit-rate applications, advanced receiver technology can be used to improve coverage. Indeed, the technology has the potential to double the high-bit-rate coverage of a mildly dispersive channel.

The technology also helps existing low-bit-rate applications, such as voice, by improving capacity 30% to 34%.

The generalized-Rake (G-Rake) receiver, which is based on current Rake receiver technology, will evolve to support multiple receive antennas, further benefiting high-bit-rate coverage.

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