Radio Interface Performance of EDGE, a Proposal for Enhanced Data Rates in Existing Digital Cellular Systems

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Abstract — **The use of alternative modulation to provide Enhanced Data rates for Global Evolution (EDGE) is currently being standardized for GSM by the European Telecommunications Standards Institute (ETSI), and is also adopted for IS-136 evolution by the Universal Wireless Communications Consortium (UWCC) in the US.**

In this paper, the currently proposed radio interface for this concept and first link simulation results are presented. It is demonstrated that high-level modulation is feasible with an acceptable increase of complexity, and provide good performance, even if impacts like power amplifier nonlinearity, phase noise, frequency offset, etc. are taken into account.

I. INTRODUCTION

GSM and IS-136 are both second generation cellular standards with world-wide success. As of year-end 1997, GSM is used by 67 million subscribers in 100 countries, and the IS-136 system family (incl. EIA-553 and IS-54) serves 80 million subscribers in 95 countries.

Although speech is still the main service in these systems, support for data communication over the radio interface is being improved rapidly. Current GSM products provide data services with user bit rates up to 9.6 kbps. The next steps (phase 2 and 2+) in the evolution of GSM are already in final stages of standardization, where high bit rate circuit-switched modes (high speed circuit-switched data, HSCSD) as well as packet services (general packet radio service, GPRS) have been defined [1, 2]. High bit rates are achieved with multi-slot operation, but since both HSCSD and GPRS are based on the original GMSK modulation, the increase of bit rates per time slot is moderate.

For IS-136, similar standardization activities are on-going. The combination of multi-slot operation and the new modulation scheme 8PSK enables data rates approximately four times higher than today [7].

A parallel process is the evolution of third generation systems (UMTS/IMT-2000), which will be optimized for high bit rate packet data services [5, 8]. In brief, the bit rate requirements are 384 kbps with wide area coverage, and in the order of 2 Mbps in local areas.

An evolutionary path towards providing third generation services can be obtained by further development of the existing standards. The advantages of such an approach are for instance fast availability, and use of existing GSM and IS-136 infrastructure in existing frequency bands.

Such an evolutionary path is provided by the EDGE air interface, which by combining an alternative modulation with a 200 kHz carrier bandwidth enables a significant increase of user bit rate.

EDGE was first proposed to ETSI as an evolution of GSM in the beginning of 1997. During 1997 a feasibility study [4] was completed and approved by ETSI, making way for the currently on-going standardization. Although EDGE reuses the GSM carrier bandwidth and time slot structure, it is by no means restricted from use with other cellular systems. Instead it can be seen as a generic air interface for efficiently providing high bit rates, facilitating an evolution of existing cellular systems towards third generation capabilities. Consequently, as the EDGE concept proved feasible and gained maturity, it was also evaluated and accepted within the UWCC for IS-136 evolution in January 1998.

Aspects of GSM evolution with EDGE has already been considered in [10]. However, the main focus of that paper was spectral efficiency achievable with several modulation schemes. For this, several idealistic assumptions, such as a non-dispersive channel model and perfect interleaving, were used. Furthermore, channel coding and burst structure were not optimized.

In this paper, we present the EDGE air interface as proposed in the feasibility study [4]. Furthermore, results of link simulations are shown, assuming moderately dispersive channels and realistic receivers with moderate complexity. In [6], the EDGE system concept and performance results are discussed.

In Section II, the EDGE radio interface is presented. Link simulation results are shown and discussed in Section III. Finally, conclusions are drawn.

II. EDGE RADIO INTERFACE

EDGE has been developed as an evolutionary path of existing systems towards higher data rates. One intention is to provide use of EDGE in existing GSM systems within the same frequency bands. A very likely scenario is that EDGE capable transceivers are added, or replace a conventional GSM transceivers in a cell, respectively. This feature leads to the following requirements:

- The spectrum mask of GSM should be fulfilled.
- The burst duration should be the same as in GSM.
- The system modifications, e.g. control signalling structure, should be as small as possible.

For IS-136 evolution, a separate part of the frequency band shall be reserved, so that equivalent requirements from this standard need not be considered. Therefore, the same air interface may be used for both GSM and IS-136 evolution, which is an attractive chance to lead both standards towards a common world-wide future.

A. Modulation

GMSK, which is used in GSM today, can be approximated by offset QPSK (OQPSK) with half symbol rate, or equivalently by $\pi/2$ -shift BPSK with remained symbol rate. Gross bit rate can be doubled by using an enlarged signal set via offset 16QAM (O16QAM), also called $\pi/2$ -shift QASK, which has been proposed for EDGE in [4]. It is worth noting that O16QAM is one candidate for EDGE, and modulation may be a matter for discussion during standardization.

In accordance to latter interpretation, the term 'symbol' will be used for a QASK symbol, which carries two bits of encoded information. It should further be remarked that, e.g. in [4], O16QAM and OQPSK may be denoted by Q-O-QAM and B-O-QAM, respectively.

In [10], spectral efficiency of cellular systems are compared for several linear modulation schemes. It is shown that, despite of decreased sensitivity, 16QAM may increase spectral efficiency compared to QPSK and 8PSK in typical scenarios. On the other hand, 32QAM is more inefficient in the interesting range. Therefore, 16QAM seems to be an attractive candidate for EDGE.

B. Symbol Frequency

The new modulation has a signal spectrum which can be narrowed compared to GMSK if the same symbol frequency is assumed. This effect can be exploited by an increased symbol frequency, which is additional to the increased number of bits per symbol.

In GSM, all frequencies are derived from a 13 MHz clock. An attractive symbol frequency which is reasonable from an implementation point of view is 13000/36=361.111 ksps. With this symbol frequency and a root raised cosine pulse shape with roll-off 0.5, the GMSK frequency mask is still fulfilled. In this case, symbol frequency is increased by 33%, and the total modulating bit rate for EDGE is 2.67 times as much as in GSM.

C. Channel Coding

High-level modulation is proposed for EDGE. It is well known that standard convolutional coding like in GSM is not optimum in this case. Therefore, several coded modulation schemes were studied. In contrast to most of the already published investigations, we aimed for a coding scheme that has moderate complexity, and good performance independent of the channel situation. Some results of this study are presented in [9]. The proposed scheme is similar to a multilevel code with Gray mapping, where the receiver applies independent (parallel) decoding on levels. For EDGE, the proposed implementation is one convolutional code which is punctured in accordance to the error protection requirements of the classes of levels. This scheme is called 'coding based on multiple classes of levels'. More details can be found in [9]. The used convolutional code has rate 1/2 and constraint length 7.

D. Burst Format

One requirement for EDGE is to re-use as much as possible of the existing GSM standard. Therefore, high-level modulation is introduced by replacement of normal bursts carrying traffic channel information. Therefore, the GSM burst structure and period, which is equal to 576.92 µs , is remained. Exclusively the content of the new normal bursts is different.

Each burst contains a training sequence, which comprises 26 symbols in GSM. An analysis has shown that the loss due to channel estimation is approximately independent of the used modulation scheme. An optimization of the loss versus the amount of redundancy for an assumed channel estimate with 7 taps led to the conclusion that the training sequence should comprise 28 symbols. Due to reduced symbol interval in EDGE, the time (in seconds) spent on training is even reduced compared to GSM.

The number of tail symbols is chosen as equal to two at both ends of the burst. The reason for this slightly less number compared to GSM is that less time dispersion is expected for typical EDGE scenarios. The same guard period as in GSM is assumed, which is equivalent to 12.33 QASK symbols in EDGE.

The remaining part of each burst comprises 2 x 82 symbols, which further include two stealing bits. The format of the normal bursts for both GSM and EDGE is depicted in Fig. 1.

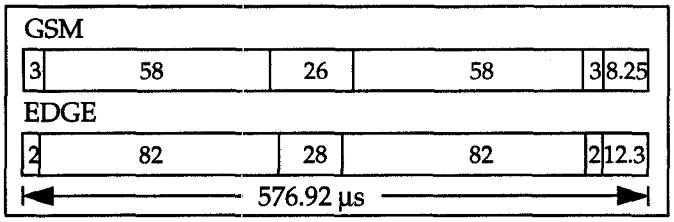

Figure 1: Normal burst for GSM and EDGE. Figures are in terms of symbols.

In total, payload of each burst comprises 326 bits. Therefore, the gross bit rate per timeslot is equal to 65.2 kbps, which is about 2.86 times as much as in GSM.

E. Link Adaptation

EDGE shall be usable in existing systems with given infrastructure. On the other hand, high-level modulation is more sensitive to noise and interference than GMSK. Therefore, enhanced data rates can be used with less probability, and an adaptive selection of the air interface mode, i.e. the coding and modulation scheme, has to be provided. This *link adaptation*, which is a key feature of the EDGE concept, may follow various strategies like maximization of throughput for packet services.

It is obvious that link adaptation should be as accurate and fast as possible. In this sense, the different symbol rates of GMSK and O16QAM may be disadvantageous. Therefore, the introduction of an additional modulation scheme, namely OQPSK, which has the same symbol frequency and pulse shaping as EDGE's O16QAM is proposed. This OQPSK provides link adaptation without switching symbol frequency.

OQPSK is used instead of GMSK in those cells on those carriers and timeslots, where EDGE is available. Therefore,

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four OQPSK schemes with different code rates are defined in accordance to the GPRS schemes. Since we assume the same payload for GPRS and the new OQPSK schemes, code rate can be reduced for the latter to provide increased link performance.

F. Packet Service

The increased data rate of EDGE can be used for many services. The most attractive one is expected to be packet data. In equivalence to GPRS, being standardized for GSM today, enhanced GPRS (EGPRS) is proposed for EDGE, comprising four schemes ECS-1 to ECS-4 with O16QAM and different average code rates. For simplified link adaptation, additional four schemes ECS-5 to ECS-8 based on OQPSK are introduced. These are used instead of CS-1 to CS-4 if EDGE services are available.

Parameters of the schemes specified in GPRS and proposed for enhanced GPRS are shown in Tables 1 and 2, respectively. It should be noted that the schemes are sorted for increasing radio interface rate, which includes signalling overhead for the RLC/MAC layer.

Table 1: Parameters of GPRS

Scheme	Modulation	Gross bit rate	Code rate	Radio interface rate
CS-1	GMSK	22.8 kbps	0.49	11.2 kbps
CS-2	GMSK	22.8 kbps	0.64	14.5 kbps
CS-3	GMSK	22.8 kbps	0.73	16.7 kbps
CS-4	GMSK	22.8 kbps	1	22.8 kbps

Table 2: Parameters of enhanced GPRS (EGPRS)

Scheme	Modulation	Gross bit rate	Code rate	Radio interface rate
ECS-5	OQPSK	32.4 kbps	0.35	11.2 kbps
ECS-6	OQPSK	32.4 kbps	0.45	14.5 kbps
ECS-7	OQPSK	32.4 kbps	0.52	16.7 kbps
ECS-8	OQPSK	32.4 kbps	0.70	22.8 kbps
ECS-1	O16QAM	65.2 kbps	0.51	33.0 kbps
ECS-2	O16QAM	65.2 kbps	0.63	41.0 kbps
ECS-3	O16QAM	65.2 kbps	0.74	48.0 kbps
ECS-4	O16QAM	65.2 kbps	1	65.2 kbps

For EGPRS, each block is mapped to four bursts, applying block interleaving over four bursts, which is also equivalent to GPRS.

G. Other Services

The main focus of EDGE activities has been packet data. But it is obvious that the increased data rate may also be suitable for other services like transparent data, and even high-quality speech may be attractive, for instance in office applications. Further investigations will be needed to cover these aspects.

III. Link Simulation Results

The performance of EDGE was estimated by means of link simulations. Again, the focus is on packet services provided by EGPRS. The benchmark is GPRS, for which simulations were performed, too.

A. Assumptions

The used channel model is typical urban (TU) [3] without antenna diversity. A very likely scenario for high rate services is a static or slowly moving mobile, so that we assumed a vehicle speed of 3 km/h. The carrier frequency is equal to 900 MHz. But it is worth noting that the system concept generally enables operation at vehicles speed as high as in GSM, even if performance of O16QAM suffers more from high speed than GMSK.

Since EDGE is considered for both GSM and IS-136 evolution, two scenarios are assumed:

- Ideal frequency hopping (FH) - modelling use of EDGE in a GSM system with sufficient number of EDGE carriers. Ideal FH means that the fading processes for consecutive bursts are uncorrelated.
- No FH - modelling use of EDGE air interface in an IS-136 system with low system bandwidth, not allowing FH.

In [6], the results presented in the following are used to determine system performance of EDGE for the interference-limited as well as for the coverage-limited case. Accordingly, link simulations were performed for the two following scenarios:

- The link is disturbed by white Gaussian noise, hence yielding the performance versus E_b/N_0, with E_b denoting energy per modulating bit.
- The link is disturbed by one cochannel interferer, hence yielding the performance versus C/I.

The receiver comprises an input filter, a synchronization and channel estimation unit, an equalizer, a deinterleaver, and Viterbi decoder. A seven-tap channel estimate is generated. The equalizer is suboptimum with approximately four times the complexity per burst compared to the 16-state Viterbi algorithm for GMSK. A comparison with the optimum equalizer for O16QAM, a Viterbi algorithm with 4096 states, which is not practicable, shows a degradation below 1 dB on the TU channel.

B. Results

The performance measure for packet services is block error rates (BLER), where a block, which is interleaved over four bursts, is considered as erroneous if at least one bit error occurred. Simulation results for both, EGPRS and GPRS, are depicted in Figs. 2-7. A typical operational point is given by BLER=20%, which is the basis for the following discussion.

The results show that the coding and modulation schemes of EDGE provide a different robustness for the various possible data rate. Therefore, link adaptation can exchange data rate versus sensitivity.

Regarding e.g. noise sensitivity in Fig. 2, required signal-to-noise ratio is increased proportionally for higher data rate. It appears that O16QAM does not generally perform significantly worse than OQPSK even on fading channels, as ECS-1 degrades by about 3 dB compared to ECS-7, both using a code with rate of about 0.5. For higher code rates however, decrease of power efficiency is higher than increase of data rate, which

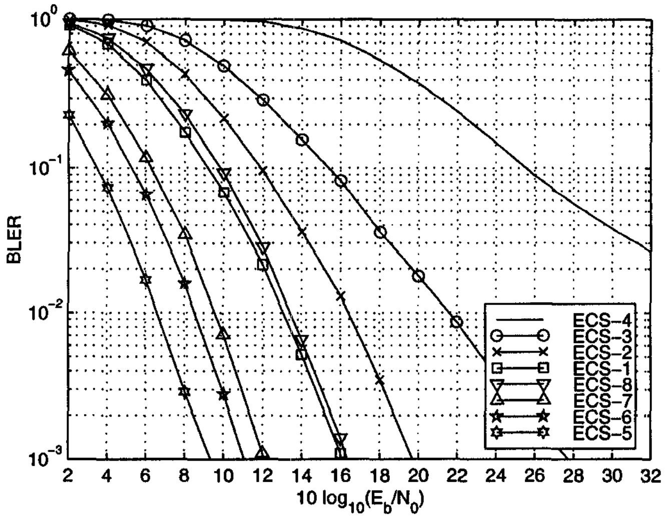

Figure 2: BLER versus E_b/N_0 for EGPRS with ideal FH

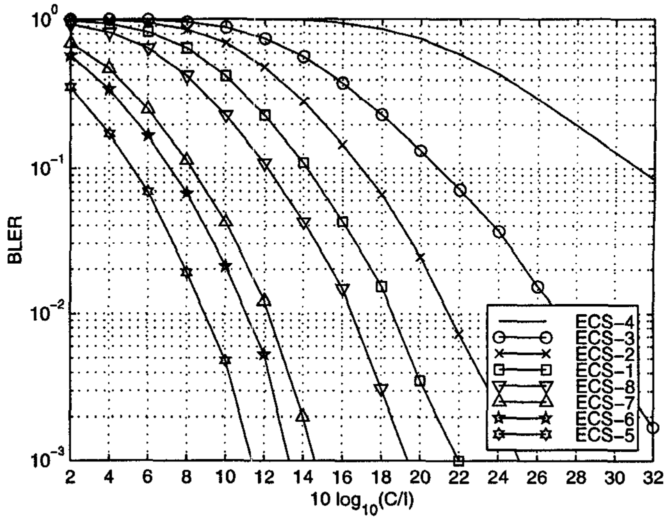

Figure 5: BLER versus *C/I* for EGPRS with ideal FH

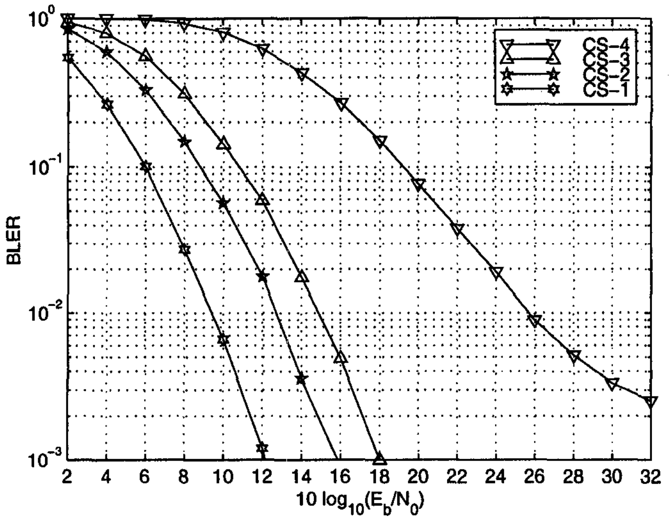

Figure 3: BLER versus E_b/N_0 for GPRS with ideal FH

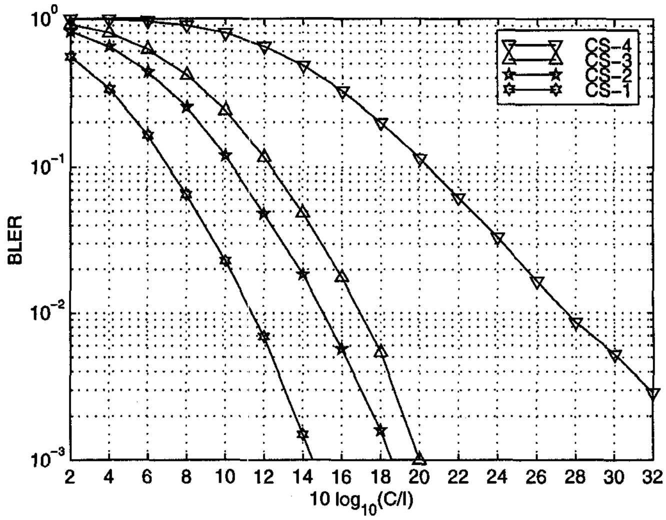

Figure 6: BLER versus *C/I* for GPRS with ideal FH

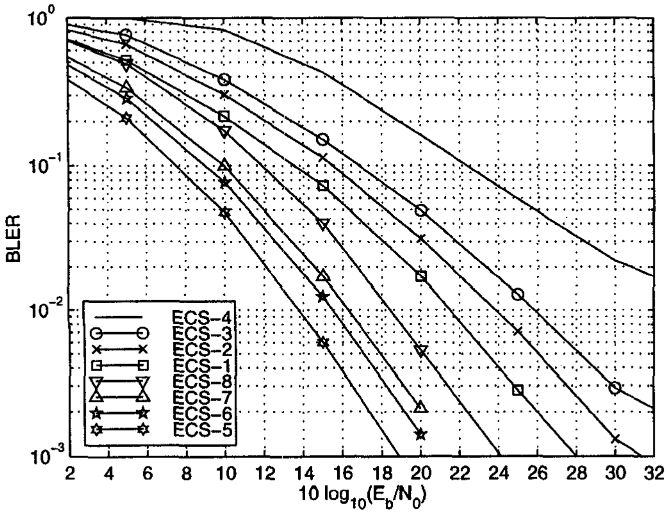

Figure 4: BLER versus E_b/N_0 for EGPRS without FH

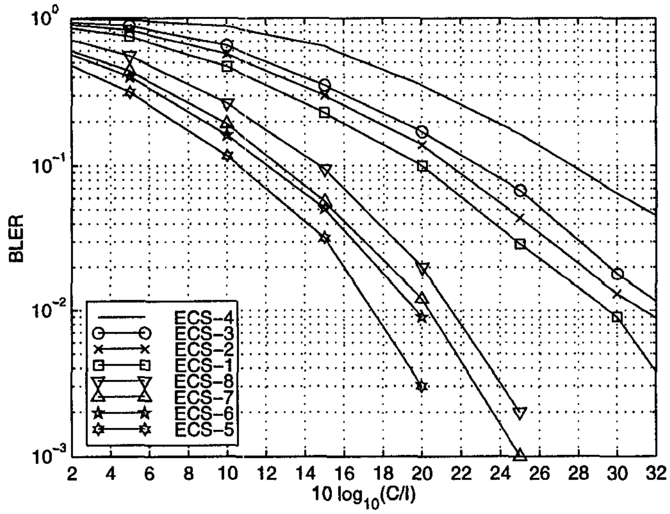

Figure 7: BLER versus *C/I* for EGPRS without FH

is a result of less code efficiency on interleaved fading channels.

Performance of EDGE packet services should be compared with GPRS results, which are depicted in Fig. 3 for noise sensitivity. It turns out that the introduction of OQPSK increases performance by 2 dB up to 4 dB while providing the same data rates as GPRS. The reason is the higher gross bit rate for OQPSK, which allows for more code redundancy.

The interferer sensitivity results in Figs. 5 and 6 are equivalent to the previous. The major difference is that interferer sensitivity is by 1.5-2 dB and 5 dB higher than noise sensitivity for OQPSK and O16QAM, respectively. This 3 dB difference between both modulation schemes is due to the doubled number of bits per symbol for O16QAM.

In Figs. 4 and 7, BLERs for channels without FH are depicted. Here, channel coding is less efficient, and all schemes with coding perform worse than previously. On the other hand, performance of the uncoded schemes, which apply the same mapping of blocks to bursts, is improved.

C. Robustness

The previously discussed results show that the EDGE air interface is feasible and provides good performance in typical mobile radio environments. However, further investigations are needed concerning robustness of the new modulation.

One important issue is the amplitude variation of the signal modulated by O16QAM. The significant Crest factor cause requirement for an linear power amplifier. In order to show its impact, simulations were performed with the model of an exemplary available power amplifier, the RF2108 of RF Micro Devices. It turned out that an input back-off of 5 dB is sufficient to fulfil the GSM spectrum mask, and to cause negligible loss for interesting error rates. It should be noted that input back-off is given relative to the 1 dB compression point, and therefore the equivalent output back-off is 1 dB less.

Besides spectrum, requirements are defined in [3] for adjacent channel protection, which should be fulfilled by EDGE, too. Simulations were performed with one adjacent channel interferer with frequency offset equal to 200 kHz and 400 kHz, respectively. The differences of the C/Is for co-channel and for adjacent channel interference at a typical raw bit error rate give the adjacent channel protection, which is summarized in Table 3 for the possible cases. Also, the GSM requirements are included.

Table 3: Adjacent channel protection of EDGE and/or GSM

Signal	Interferer	200 kHz	400 kHz
GSM 05.05		18 dB	50 dB
GMSK	GMSK	~ 20 dB	~ 64 dB
GMSK	O16QAM	~ 20 dB	~ 56 dB
O16QAM	GMSK	~ 20 dB	~ 58 dB
O16QAM	O16QAM	~ 20 dB	~ 54 dB

The results show that EDGE fulfils the GSM adjacent channel requirements, and therefore can be integrated into an existing GSM system without increasing the adjacent channel interference.

A further issue is the frequency error, which may be caused by Doppler shifts and frequency synchronization errors. The latter is restricted to 0.1 ppm in GSM05.10, which is equivalent to about 100 Hz for GSM900, and 200 Hz for PCS1900. The impact can be reduced by an automatic frequency control (AFC) algorithm. Simulations were performed for EDGE using an AFC algorithm which has not been optimized for O16QAM. As expected, O16QAM is more sensitive to frequency errors than GMSK, but it still leads to acceptable performance at relatively high frequency errors. As an example, the degradation at a raw bit error rate of 1% is about 1.5 dB for a frequency error of 300 Hz.

Although low speed mobiles are expected to be typical for EDGE services, high velocities are possible. Simulations show a higher sensitivity of O16QAM compared to GMSK. But degradation is acceptable if the speed is not too high. Exemplarily, the loss at a block error rate of 20%, which is a typical operational point for packet services, is about 2 dB at 100 kmph.

IV. Conclusions

In this paper, a radio interface for EDGE is proposed which provides an evolutionary path of existing cellular standards like GSM and IS-136 towards higher bit rates, and hence approaching IMT-2000 requirements. Packet data transmission is a very attractive EDGE application, and therefore is the focus of this paper. But the increased data rates can also be beneficial for other services like transparent data and high-quality speech. For instance, multislot transmission in GSM may be substituted by an EDGE service on a less number of timeslots, hereby reducing complexity for remained data rate.

Simulation results are presented, which show that offset 16QAM is feasible, and provides good performance in mobile radio systems in a variety of realistic radio conditions.

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