APPLICATION OF GSM IN HIGH SPEED TRAINS: MEASUREMENTS AND SIMULATIONS

Manfred Göller

Abstract
The paper presents results of measurements and simulations concerning the application of the European GSM system in high speed trains travelling at up to 500 km/h. The aim is to answer the question to what extent GSM (performance specified up to 250 km/h) can cope with the high velocities which are demanded for future railways. Measurements along railway lines have shown that a railway mobile radio channel results in better performance (Rice channel) than standard mobile radio channels (Rayleigh or weak Rice channel, see GSM-Rec's).
BER and block error rate of GSM traffic channels up to 500 km/h are simulated. Comparison of the results at 250 km/h and 500 km/h shows that the GSM high velocity problem can be solved either by increasing the SNR by about 2dB or by increasing the Rice parameter c by about 6dB (numerical values for profile RA = rural area; railway channel with c = 6dB against standard channel with c = 0dB), i.e. the BER at 500 km/h (railway channel) is not worse than the BER at 250 km/h (standard channel).
A simple example shows that the benefit in the transmission of telegrams consisting of blocks of decoded bits can be much higher.
The desired channel performance, i.e. a strong direct path (high Rice parameter), can be achieved by careful radio coverage planning along the railway line. This means a GSM standard receiver is sufficient to cope with the GSM high velocity problem and no additional means are needed.

1. Introduction

The present situation of mobile communications in the European railways is characterized by a multitude of different networks using various analog technologies. No common solution exists and the systems are not compatible. This situation does not satisfactorily reflect the current process of integration within the European Community.
Considering this, the German Railway is working on a solution with GSM which is in correspondence with a decision of the UIC (Union internationale de chemin de fer) [1].
Future high-speed trains in Europe are to reach velocities up to 500 km/h.
Thus for GSM application the question arises to what extent GSM (performance specified up to 250 km/h) can cope with the high velocities.
Useful but expensive measures against this limitation are antenna diversity or a fast adaptive equalizer.
Railway radio channels are characterized by a coverage in the form of a line along straight railway embankments, cuttings and tunnels. The antennas are situated close to the railway line, their heights are relatively small and the coverage range is limited to some few kilometers.
The environment typical to railways suggests that the railway mobile radio channel is a Rice channel, which results in better performance e.g. BER than a standard Rayleigh channel. This assumption led to radio channel measurements on lines of German Railway, modeling this channel on a computer and simulating the performance of GSM. The results of the investigations reported below contribute towards a decision as to the suitability of GSM for high-speed railway communication.

2. Radio channel measurements

The radio channel measurements were carried out on lines of German Railway including new built high velocity lines. The radio channel is completely characterized by its complex, time variant impulse response h (T, t), with T = delay time, t = real time.

Measuring equipment

The impulse response was measured with the channel sounder RUSK400. It's measurement limits are ΔT_{min} = 5µs and σ_{Tmin} = 1,4µs delay spread which is sufficient for GSM.

M. Göller is with the DETECON GmbH, Bonn, Germany

Measuring conditions

- Frequency band 945 MHz
- Transmitter power 20W ... 50W
- Transmitting antenna height above rail level
  open terrain h_1 = 14m, 20m, tunnel h_1 = 4m.
  The antenna is situated close to the railway line.
- Polarization vertical
- Receiving antenna height h_2 = 4,3m, omnidirectional, mounted on the top of the measuring coach.
- Measuring distance transmitter-receiver d = 0, 1, 3, 5 km
- Measuring interval s_0 = 150 ... 200m

Channel parameter

The received process

$$r(t) = r_s(t) \cdot r_l(t) = \sqrt{\sum_{k=1}^{L} |h(T_k, t)|^2}$$

consists of a fast part $r_s(t)$ (Rayleigh or Rice fading) and a slow part $r_l(t)$ (lognormal fading).
Of interest is the dynamic behaviour of the channel which is determined by the fast fading $r_s(t)$.
By low-pass filtering of the received process r(t) one gets $r_l(t)$ and after division $r_s(t) = r(t)/r_l(t)$.
In particular the Rice parameter

$$c = P_d/P_m = \begin{cases} \infty \; ; \; P_m = 0 \; ; \; Gau\beta \quad channel \\ 0 \; ; \; P_d = 0 \; ; \; Rayleigh \quad channel \end{cases}$$

is defined as the power ratio of the signal in the direct path to the multipath-spread signals. It is estimated by the aid of a chi-square-test by comparison of the theoretical Rice-distribution with the measured empirical distribution of the fast fading [2].
Additional characteristics of the fast fading are mean value $\overline{X}$[dB], standard deviation σ_X[dB] and mean fading depth

$$\Delta X[dB] = X(90)\text{-}X(10),$$

where X(90) and X(10) are the 90% and the 10% quantile of the empirical distribution function P(x<X) of the signal level x[dB] respectively.
For Rayleigh fading one gets

$$\bar{x} = -2{,}51dB, \quad \sigma_x = 5{,}57dB, \quad \Delta X = 13{,}39dB.$$

For further details of channel characterization see [2], [3] and [4].

3. Measuring results

Fig. 1 shows as an example results of measurements at Milbertshofen, a Marshalling yard and industrial area near Munich (Bavaria).
As can be seen from the delay-Doppler-spectrum (scattering function) and the Doppler spectrum, the measuring train moves towards the transmitter (angle of incidence = 0°, maximum Doppler frequency $+f_{Dmax}$). A strong direct path exists with a delay of zero (main impulse) and a spike at $+f_{Dmax}$. A weak reflection behind the train (angle of incidence = 180°, maximum Doppler frequency $-f_{Dmax}$) occurs at a delay of 8,6µs related to the main impulse (compare with the impulse response and the delay spectrum). It results from a highway bridge crossing the line 1,3km behind the measuring train.
The multipath propagation is weak and in the order of the measuring limits. At locations where deep fadings occur the delay spread and the delay window are higher.
Mean value $\overline{P}_S$, standard deviation σ_S and mean fading depth $\overline{\Delta P}_S$ of the fast fading already show that $r_S(t)$ is a Rice-process (compare with the theoretical results above for a Rayleigh process). A high Rice parameter corresponds to small standard deviation and small mean fading depth and reversed.
A summary of measuring results is shown in table 1. For further details see [2], [3] and [4].
In particular the results show that in the delay plane at all investigated railway lines only weak multipath propagation was measured. These channels can be described by a delay spectrum RA (rural area) or TU

(typical urban) as specified in GSM-Rec. 05.05. Exception are lines in the Alps which can be characterized by the delay spectrum HT (hilly terrain). RA applies for tunnels.

It should be noted furthermore that in the Doppler plane for a coverage along the line a direct path was always measured. The measured Rice parameter was about c = 8...13dB, see table 1. This means that in the Doppler plane railway mobile radio channels (Rice) are better than standard mobile radio channels (Rayleigh) as specified in GSM Rec. 05.05.

The results suggest to model a railway mobile radio channel by

- a delay spectrum as defined in GSM-Rec. 05.05 and
- a Doppler spectrum also as defined in GSM-Rec. 05.05 but superimposed by a single spectral line resulting from a direct path. It's strength is determined by the Rice parameter.

Thus the typical railway mobile radio channel is a Rice channel superimposed by a slow, lognormal fading.

location	**fast fading**				**slow fading**
	delay spectrum	Doppler spectrum	Rice parameter		stand. dev.
			$\bar{C}$ [dB]	σ_c [dB]	σ_l [dB]
Freudensteintunnel, NBL	RA	Rice	17,5	4,2	1,2
Kraichtal, NBL	RA...(TU)	Rice	10,8	4,9	2,9
Glems, NBL	RA...(TU)	Rice	9,5	3,6	3,7
Eichstätt	RA...(TU)	Rice	13,0	2,3	3,2
Ostermünchen	RA...(TU)	Rice	10,8	2,4	3,7
Oberau - Garmisch	HT	Rice	12,8	2,1	2,2
Oberau - München	HT	Rice	10,0	2,4	1,9
Milbertshofen	RA...(TU)	Rice	8,2	2,0	3,7

Table 1: Summary of channel measuring results under standard measurement conditions: distance d=3km; transmitter: beam antenna 51° horizontal, gain 10,3dBd, height h_1=20m, tunnel h_1=4m; receiver: omnidirectional antenna, heigth h_2=4,3m; NBL=newly built high speed line; (xx)=less frequent.

4. Simulation results

To simulate a railway mobile radio channel a 6-path-model as specified in GSM is used. The direct path is superimposed on the first path so that quite arbitrary Rice parameters can be generated.

The simulations were focused to standard GSM-channels RAx and railway channels RAxy, where RA = terrain profile rural area, x = velocity in km/h and y = Rice parameter in dB.

Fig. 2 shows as an example simulation results of the half-rate traffic channel TCH/H2,4 after convolutional decoding (code rate r = 1/3, interleaving depth I = 19, interleaving delay = 185ms).

With respect to statistical safety and appropriate simulation time only BER$\geq 10^{-5}$ were simulated.

The results from Fig. 2a show that [5], [6]

- the BER goes up when the velocity increases from 250km/h to 500km/h;
- the rise of BER can be compensated by increasing the SNR by about 2dB (see also [7]);
- the rise of BER can be compensated by increasing the Rice parameter from c = 0dB (GSM channel) to c = 6dB (railway channel);
- the BER at 500km/h with the railway channel RA500,6 is not worse than the BER at 250km/h with the standard GSM channel RA250.

Block error rate

In data communications K information bits are combined in blocks or telegrams. A block or telegram is wrong if it contains ≥ m wrong bits. Then P (≥ m; K) is the cumulative probability that in a block with a length K are at least m wrong bits. Especially m = 1 describes the block error probability and m = g > 1 the probability that a block contains errors with a weight ≥ g.

Figures 2.b...2.d show the cumulative block error rate of TCH/H2,4 for SNR = 5dB. Table 2 shows the results for blocks of K = 256 information bits. Automatic train control could be a possible application of this example.

It can be stated that with a railway channel not only the BER, but more important, the cumulative block error rate is reduced as well, actually the more the higher the error weight is.
For example, if we assume an additional error detection after the TCH/H2,4-decoding which can detect errors up to a weight $e = d - 1 = 7$ over $K = 256$ bits then $P(\geq 8; 256)$ is the residual block error rate. Comparing RA500,6 and RA500,0, the railway channel provides a factor of 1/10 or 1/38 respectively, by which the block or residual error rate is smaller.

channel	standard GSM RA 250	standard GSM RA 500,0	railway RA 500,6
BER	$1{,}3 \cdot 10^{-4}$	$1{,}3 \cdot 10^{-3}$	$7{,}7 \cdot 10^{-5}$
$P(\geq 1; 256)$	$8{,}2 \cdot 10^{-3}$	$5{,}7 \cdot 10^{-2}$	$5{,}9 \cdot 10^{-3}$
$P(\geq 8; 256)$	$9{,}9 \cdot 10^{-4}$	$1{,}2 \cdot 10^{-2}$	$3{,}2 \cdot 10^{-4}$
$P(\geq 64; 256)$	$< 10^{-6}$	$3{,}8 \cdot 10^{-5}$	$< 10^{-6}$

Table 2: Cumulative block error rate of the TCH/H2,4 at SNR=5dB and a telegram length $K = 256$.
Radio channel RAx,y = rural area with velocity x[km/h] and Rice parameter y[dB].

5. Example

The following simple example illustrates, for the case of automatic train control, to what extent the performance is influenced by the radio channel. The results are to be understood as an upper limit which is achievable more effectively by an appropriate error detecting or error correcting code.
Suppose that information blocks (telegrams) of the length $K = 256$ are transmitted n times in the TCH/H2,4 with a block error rate $p = P(\geq 1; 256)$ as shown in table 2 for SNR = 5dB.
Statistical independence assumed, table 3 shows the probability

- $P_n = p^n$
  that all n transmitted blocks are wrong (residual error rate),
- $Q_n = (1-p)^n$
  that all transmitted blocks are right and
- $Q(\geq 1; n) = 1-p^n$
  that at least one of the transmitted blocks is right (throughput, availability).

Comparing again RA500,6 (railway) and RA500,0 (standard), the results show that a factor of 1/10 in the block error rate of the RA500,6 provides a multiple of powers of ten already for one of the simplest codes, the multiple transmission.
This means that at 500km/h any given code provides a higher transmission security if a railway channel can be assumed.

channel	standard GSM RA 250			standard GSM RA 500,0			railway RA 500,6		
BER	$1{,}3 \cdot 10^{-4}$			$1{,}3 \cdot 10^{-3}$			$7{,}7 \cdot 10^{-5}$		
$P(\geq 1; 256)$	$8{,}2 \cdot 10^{-3}$			$5{,}7 \cdot 10^{-2}$			$5{,}9 \cdot 10^{-3}$		
n	1	3	10	1	3	10	1	3	10
P_n	$8{,}2 \cdot 10^{-3}$	$5{,}5 \cdot 10^{-7}$	$1{,}4 \cdot 10^{-21}$	$5{,}7 \cdot 10^{-2}$	$1{,}8 \cdot 10^{-4}$	$3{,}6 \cdot 10^{-13}$	$5{,}9 \cdot 10^{-3}$	$2{,}0 \cdot 10^{-7}$	$5{,}1 \cdot 10^{-23}$
Q_n	0,992	0,976	0,921	0,943	0,839	0,556	0,994	0,982	0,942
$Q(\geq 1; n)$	0,992	$0{,}9_6 4$	$0{,}9_{20} 9$	0,943	0,9998	$0{,}9_{12} 6$	0,994	$0{,}9_6 8$	$0{,}9_{22} 5$

Table 3: Probabilities for n-times transmission of a block of $K = 256$ information bits in the TCH/H2,4. Comparison of standard GSM and railway channels at SNR = 5dB. (e.g. $0{,}9_3 8$ means 0,9998 or $1\text{-}2 \cdot 10^{-4}$).

6. Summary and conclusions

The paper presents results of mobile radio channel measurements in a railway environment. The results show that in general a railway mobile radio channel is a Rice channel with better quality (higher Rice parameter) than standard GSM channels.

Simulation results of TCH/H2,4 with terrain profile RA show that the high-velocity problem of GSM at 500km/h can be solved either by increasing the SNR by about 2dB or by increasing the Rice parameter from c = 0dB (standard GSM channel) to c = 6dB (railway channel). In this case BER and block error rate at 500km/h are not worse than at 250km/h with a standard channel.

A simple example shows that, if a railway channel can be supposed, the benefit of smaller BER and block error rate is gained when telegrams are to be transmissioned.

The desired channel performance, i.e. a strong direct path (high Rice parameter), is achievable by carefully planning the radio coverage along the railway line. This has the benefit that a GSM standard receiver can cope with the high speed problem and no additional, expensive means like antenna diversity or fast adaptive equalizer are needed.

Acknowledgement

The author is indebted to Dipl.-Ing. W. Lautenschlager and Dipl.-Phys. P. Hill from the German Railway, who were involved in preparation, organization and carrying-through the measurements and to his colleagues Dipl.-Phys. G. Fröhlingsdorf, Dipl.-Ing. K. D. Masur and Dipl.-Ing. U. Weber for their helpful and engaged work in analyzing the measuring results and carrying-out the simulations.

Literarture

[1] M. Göller, D. Münning, H. Rauch, G. Sänger: A future European integrated railway mobile network based on GSM.
Proc. Fifth Nordic Seminar on Digital Mobile Radio Communications. DMRV, 1-3 Dec. 1992 Helsinki.

[2] M. Göller, K. D. Masur, G. Fröhlingsdorf, U. Weber: Meßergebnisse und Parameter zur Modellierung von Bahn-Mobilfunkkanälen im 900-MHz-Band.
Nachrichtentechnik-Elektronik, Berlin 43 (1993) No. 6, pp. 290-295.

[3] M. Göller, K. D. Masur: Ergebnisse von Funkkanalmessungen im 900-MHz-Bereich auf Neubaustrecken der Deutschen Bundesbahn.
Nachrichtentechnik-Elektronik, Berlin 42 (1992), No. 4, pp. 143-146, No. 5, pp. 206-209.

[4] M. Göller: Radio channel measurements on lines of German Railway (Deutsche Bundesbahn) in the 900 MHz frequency band.
COST 231 TD (92) 20, Vienna 7-10 Jan. 1992.

[5] M. Göller, U. Weber, G. Fröhlingsdorf: Results of simulations with railway mobile radio channels for high-speed applications of GSM.
ETSI/STC/SMG2 TDoc 260/1993.

[6] M. Göller, K. D. Masur, U. Weber, G. Fröhlingsdorf: Simulationsergebnisse mit Bahnmobilfunkkanälen und speziellen Bahnszenarien.
Internal report, 15.11.93.

[7] Performance of GSM with high vehicular speed. (AEG Mobile Communications)
ETSI/STC/SMG2 TDoc 97/1992.

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | sales@docketalarm.com | 1-866-77-FASTCASE

fastcase® Smarter legal research.