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Link budget comparison of different mobile communication systems based on EIRP and EISL

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Abstract. The metric EISL (Equivalent Isotropic Sensitivity Level) describing the effective sensitivity level usable at the air interface of a mobile or a basestation is used to compare mobile communication systems either based on time division or code division multiple access in terms of coverage and emission characteristics. It turns out that systems that organize the multiple access by different codes rather than different timeslots run at less emission and offer greater coverage.

1 Introduction

Mobile communication systems are evolving and new ones are added. For instance HSDPA (High Speed Downlink Packet Access) is added to UMTS (Universal Mobile Telecommunication System). It is desirable to have a clear understanding of the pros and cons of each system and the gains obtained in each evolution step. This article mainly focuses on the characteristics of mobile communication systems in terms of emission and coverage capabilities.

Besides scientific interests of understanding those characteristics for each system there are also strong business implications, which are critical for the financial success of mobile operators. Operators often have to run systems in parallel, or they have to make decisions on the selection of a certain system, which is linked to huge investments over a long period. Of course it has to be noted that capacity capabilities and spectral efficiency are further critical characteristics, but this is beyond the scope of this article.

Operators become more and more global players and are working on global standard strategies to offer their customers international roaming. A worldwide standard evolution strategy is linked to even higher investments and higher financial risks.

Figure 1 illustrates the great variety of mobile communication systems and their evolution steps. A major evolution step is a migration from so-called second generation systems (2G) like IS136-TDMA (Time Division Multiple Access) and GSM (Global System for Mobile communication) towards third generation systems (3G, IMT2000 systems) like UMTS and CDMA2000 (Code Division Multiple Access). EDGE (Enhanced Data rates through GSM Evolution) is not considered a 3G system here, because it is not able to offer Quality of Service (QoS) control, what is mandated with 3G systems by the ITU (International Telecommunications Union). A further evolution of EDGE called GERAN (GSM EDGE Radio Access Network) will be able to offer that, but this standard doesn't have a wide acceptance yet.

In this article systems are compared based on their uplink, because the cell radius is mainly determined by the limited transmit power available from the mobile and the basestations sensitivity. Looking at the uplink first is also the usual procedure with RF network planning. The downlink can normally be adjusted to balance the uplink by selecting a power amplifier of appropriate size at the basestation.

In the following a methodology first introduced in Fischer et al. (2002) is used. It allows assessment of the effective usable sensitivity at the air interface of a receiving system, through a metric named EISL (Equivalent Isotropic Sensitivity Level). It follows the same philosophy as EIRP (Equivalent Isotropic Radiated Power, Meinke and Gundlach, 1992). Both metrics EIRP and EISL are power metrics measured in Watt or respectively dBm. EISL is a metric that covers aspects of the receiving systems RF installation like antenna, RF cabling and receiver's noise as well as aspects of its digital signal processing in terms of equalization and decoding. EISL allows to describe the characteristics of RF and signal processing in a joined metric. In that way it allows also to trade off efforts in RF and signal processing against each other.

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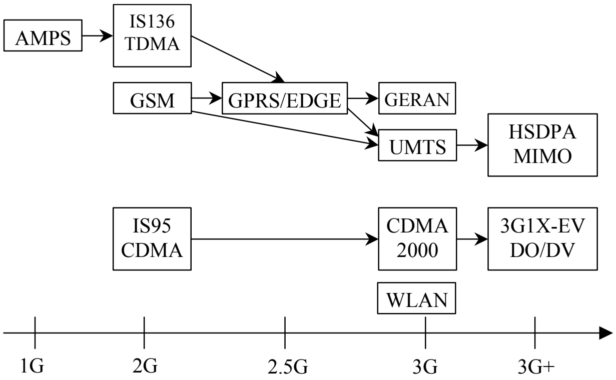

Fig. 1. Evolution of mobile communication standards.

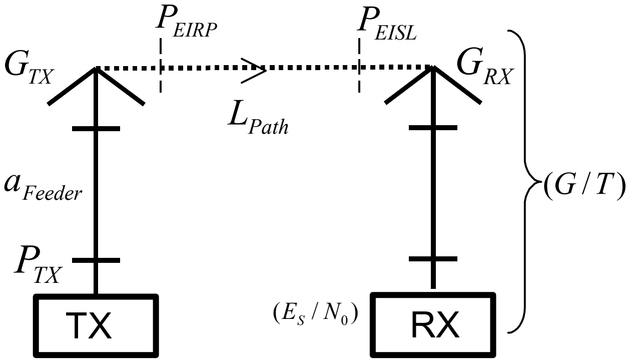

Fig. 2. Radio link metrics.

2 Equivalent isotropic sensitivity level EISL

2.1 Basic approach

As already noted in the introduction, EISL is defined in a similar way as EIRP. Let us first recover the definition of EIRP. It equals the power that would have to be fed into an ideal lossless omnidirectional antenna to create the same receive power as in the main beam direction of a directive antenna. EIRP values are typically much higher than usual power figures known from power amplifiers. This occurs especially for those cases where a high gain antenna is used with the transmitter system. Equivalently EISL is defined as the sensitivity a receiver would need to have if connected to an ideal lossless omnidirectional antenna to provide the same receive quality e.g. measured in terms of bit, frame or block error rate (BER/FER/BLER) as with a receiver connected to a directive antenna with the main beam focusing on the transmitter (Fischer et al., 2002). EISL values are typically much less than sensitivity figures measured at receiver inputs. Like with EIRP this especially happens if a high gain antenna and low noise amplifiers are used with the receiving system. EISL values can even be significantly lower than the physical limit given by the fundamental noise floor determined by the Boltzmann constant.

2.2 Definition of EISL

The following Fig. 2 shows a basic radio link. It defines the essential parameters the metrics, EIRP and EISL are dependent on.

At the transmitter system EIRP is a function of transmit power, the feeder loss and the transmit antenna gain:

$$P_{\mathrm{EIRP}}=f\,(P_{\mathrm{TX}},\ a_{\mathrm{Feeder}},\ G_{\mathrm{TX}})\,. \tag{1}$$

EIRP describes the whole transmit arrangement and thus reflects the effective usable power available at the air interface. Therefore it needs to include all gains and losses in the RF path of the transmit system.

At the receiving system, EISL is dependent on the performance of the digital signal processing stage, E_S/N_0, the quality factor G/T of the RF installation and the receive antenna gain G_{RX}:

$$P_{\mathrm{EISL}}=f\,(E_S/N_0,\ G/T,\ G_{\mathrm{RX}})\,. \tag{2}$$

EISL describes the whole receive arrangement. It reflects the effective usable sensitivity offered at the air interface and therefore includes all gains and losses in the RF and digital path of the receiving system. The quality factor G/T describing RF performance is a metric commonly in use with radio astronomy and satellite antennas (Zinke and Brunswig, 1979; Meinke and Gundlach, 1992). It reflects the gain to noise ratio of the RF installation and therefore includes all noise sources in the receive chain.

2.3 Link budget calculation philosophy

Based on EIRP and EISL the link budget can simply be analysed: The requirement that a link can be established at a certain quality is given by:

$$L_{\mathrm{Path},\,dB}\le P_{\mathrm{EIRP},\,dBm}-P_{\mathrm{EISL},\,dBm}\,, \tag{3}$$

whereby L_{Path} denotes the path loss. For equal sign the maximum acceptable path loss is obtained:

$$L_{\mathrm{Path},\,dB,\,\max}=P_{\mathrm{EIRP},\,dBm}-P_{\mathrm{EISL},\,dBm}\,, \tag{4}$$

which can be converted into a cell radius according to ETSI (1998).

2.4 G/T calculation

The same equation used with dish antennas for satellite reception (Meinke and Gundlach, 1992) can also be applied to a basestation receiving system. Thus we have:

$$\frac{G}{T}=\frac{\eta\cdot D_{\mathrm{RX}}}{\eta\cdot T_{\mathrm{Ant}}+(1-\eta)\cdot T_0+(F-1)\cdot T_0}\,, \tag{5}$$

whereby G/T reflects the RF figure of merit, D_{RX} the directivity of the receive antenna, η the antenna efficiency, T_{Ant} the equivalent antenna noise temperature, T_0 the environmental temperature and F the cascaded noise figure of the RF chain.

Looking at the denominator in Eq. (5), three sources of noise can be identified. The first term reflects the noise power caused by the effective antenna brightness temperature. It is weighted with the efficiency of the antenna to account for the attenuation inside the antenna. The second term is related to the noise caused by the losses inside the antenna. Therefore the environmental temperature of the surrounding is used. Historically the third term related to the cascaded noise figure dominated the total noise. It reflects the noise of the whole RF processing based on the cascaded noise figure. However given recent advances in low noise amplifiers this term no longer dominates the total noise. It can be observed that nowadays a much more careful modeling of the equivalent antenna noise temperature T_{Ant} is needed (see also Fischer et al., 2002). T_{Ant} has to be obtained by convoluting the three dimensional beam pattern of the antenna with the elevation dependent brightness temperature.

The simple approach to model the antenna as a resistor at environmental temperature like it was done so far with network planning is too pessimistic. It predicts a too high noise floor and therefore implies smaller cell sizes than possible. This means that more cell sites are set-up than really needed. The difference between the exact model based on G/T versus the simple model based on a resistor can easily be 1 or 2 dB, which has strong implications on link budgets and thus cell planning. For instance a 1 dB better link budget means 15% greater cell size and 13% less basestations, see Fischer et al. (2002).

2.5 Example calculation

If some usual parameters are assumed: Gain of receive antenna $G_{\text{RX},dB}=15\,dBi$ $(G_{\text{RX}}=\eta\cdot D_{\text{RX}})$, antenna efficiency $\eta=92\%$, equivalent antenna noise temperature $T_{\text{Ant}}=200\,\text{K}$, environmental temperature $T_0=290\,\text{K}$ and cascaded noise figure of RF chain $F_{dB}=6\,\text{dB}$, we obtain with Eq. (5):

$$\left(\frac{G}{T}\right)_{\text{dB}}=-15.3\,\text{dB/K}. \tag{6}$$

Just for comparison, typical values with radar telescopes are +30…45 dB/K and with home satellite dish antennas are +6…14 dB/K (Meinke and Gundlach, 1992).

2.6 EISL calculation

For the derivation of EISL it is assumed that the signal to noise ratio S/N with a receiving system at the interface between RF and digital signal processing in front of the channel selection filter within a given equivalent noise bandwidth B_{Noise} is identical looked either from the RF or from the digital side.

The derivation of the equivalent noise bandwidth with the channel selection filter is considered uncritical as it drops out of the EISL calculation. The reason for this is that essentially the noise density in terms of W/Hz is the determining factor. Instead of forcing identical SNRs also identical Energy per symbol could have been demanded. SNR was selected due to reason that it has a more practical meaning.

The interface between RF and signal processing is being looked at from both sides. Let us first look from the RF side:

$$\left(\frac{S}{N}\right)_{\text{RF}}=\frac{G}{T}\cdot\frac{P_{\text{EISL}}}{k\cdot B_{\text{Noise}}} \tag{7}$$

with k being the Boltzmann constant:

$$k=1.38\cdot 10^{-23}\frac{Ws}{K} \tag{8}$$

and then from the digital side:

$$\left(\frac{S}{N}\right)_{\text{Digital}}=\frac{ES}{N_0}\cdot\frac{r_{\text{Symbol}}}{B_{\text{Noise}}}, \tag{9}$$

whereby r_{Symbol} means the symbol rate of the used modulation format. As stated above both have to be equal:

$$\begin{aligned}
\left(\frac{S}{N}\right)_{\text{RF}}&=\left(\frac{S}{N}\right)_{\text{Digital}}\\
\frac{G}{T}\cdot\frac{P_{\text{EISL}}}{k\cdot B_{\text{Noise}}}&=\frac{E_S}{N_0}\cdot\frac{r_{\text{Symbol}}}{B_{\text{Noise}}}\\
P_{\text{EISL}}&=\frac{E_S}{N_0}\cdot\frac{1}{G/T}\cdot\left(k\cdot r_{\text{Symbol}}\right)\\
P_{\text{EISL, dBm}}&=\left(\frac{E_S}{N_0}\right)_{\text{dB}}-\left(\frac{G}{T}\right)_{\text{dB}}+10\cdot\log_{10}\left(k\cdot r_{\text{Symbol}}\right) \qquad (10)
\end{aligned}$$

Looking at the EISL equation there are 3 terms that are added up. The first term characterizes the digital signal processing section through E_S/N_0, the second one the RF section through G/T and the third one covers constants that are system dependent. From this equation it is apparent that EISL allows merging the performance metrics for RF and digital part into a joined one.

2.7 EISL parameter dependency

Detailed parameter studies can be found in Fischer et al. (2002), however a quick summary is provided here. Given the fact that today's basestations incorporate very low noise RF frontends based on transistors with 0.4 dB noise figure, basestations with 1 dB noise figure got commodity. With typical feeder cables of 3 dB loss and a loss of 2 dB inside the antenna combiner structure, a typical value of 6 dB for the cascaded noise figure is obtained. However if installations with tower mounted low noise amplifiers are considered, the cascaded noise figure may go down to 4.1 dB and with active antenna elements it may come down to even 1.9 dB. Those noise figure variations do not translate 1 to 1 into EISL variations, because with low noise figure the other noise sources get more and more important. EISL may vary by 5 dB if F_{dB} varies by 4 dB. Such an effect occurs especially if the antenna is fairly “cold”.

For low noise figures, EISL gets also strongly dependent on seasonal changes and the downtilt of the antenna. As the ground typically is much warmer than the cold sky, the equivalent antenna noise temperature T_{Ant} raises if the beam more and more points towards the “warm” ground.

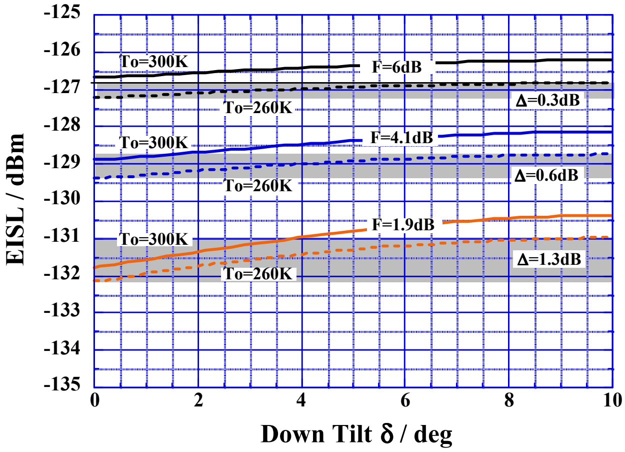

Fig. 3. EISL parameter study (Fischer et al., 2002), environmental temperature.

The variations related to seasonal and downtilt changes in Fig. 3 may be easily up to 1.5 dB (Changes due to downtilt shaded in Fig. 3). These changes have to be related to performance improvements in established signal processing structures for stable standards, which are often limited to less than 0.5 dB.

3 Application to various standards

As stated in the introduction, for coverage and link budget analysis the uplink is the critical path. Further as emission typically is dominated by the handset located next to the head and not by basestations that are farer away and even run higher power, a focus on uplink can be justified.

The comparison considers a basic 12.2 kbit/s voice service in an urban environment. Of course it is desirable also to perform such comparisons for data services, but that is part of ongoing studies.

3.1 GSM-uplink

For the calculation of a GSM mobile's EIRP, the following assumptions are made: Transmit power $P_{\text{TX, dBm}}$=20 dBm, antenna gain $G_{\text{TX, dBi}}$=+1 dBi and body loss $A_{\text{Bodyloss, dB}}$=3 dB. This results in an EIRP of:

$$\begin{aligned} P_{\text{EIRP,dBm}} &= P_{\text{TX}} + G_{\text{TX, dB}} - A_{\text{Bodyloss, dB}} \\ &= (29 + 1 - 3)\ \text{dBm} \\ &= 27\ \text{dBm}. \end{aligned} \tag{11}$$

The following calculation of the GSM base station's EISL is based on these parameters: Normalized sensitivity E_S/N_0=5 dB, RF figure of merit G/T=−15.3 dB, symbol rate r_{Symbol}=270 k_{Sym}/s. These parameters are put into Eq. (10) and this leads to:

$$\begin{aligned} P_{\text{EISL, dBm}} &= \left(\frac{E_b}{N_0}\right)_{\text{dB}} - \left(\frac{G}{T}\right)_{\text{dB}} + 10\cdot\log_{10}\left(k\cdot r_{\text{Symbol}}\right) \\ &= \left[5-(-15)+10\cdot\log_{10}\left(1.38\cdot 10^{-23}\cdot 270\cdot 10^{3}\right)\right]\ \text{dBW} \\ &= -124.3\ \text{dBm}. \end{aligned} \tag{12}$$

Typical sensitivity figures referred to a basestations antenna connector are around −112 dBm and the physical limit for the fundamental noise floor is around −121 dBm. Once again, EISL is a virtual performance metric convenient for link budget calculation like EIRP.

From Eqs. (11) and (12) the maximum allowable pathloss for the GSM uplink case can be derived:

$$L_{\text{Path, dB, max}} = 27\,\text{dB} - (-124.3\,\text{dBm}) = 151.3\,\text{dB}. \tag{13}$$

3.2 IS136-TDMA-uplink

For IS136-TDMA some system dependent parameters of course change compared to the GSM case (Coursey, 1999), but parameters related to the RF processing are kept fixed for a fair comparison.

The derivation of an IS136-TDMA mobile's EIRP is based on these assumptions: $P_{\text{TX, dBm}}$=28 dBm, $G_{\text{TX, dBi}}$=+1 dBi, $A_{\text{Bodyloss, dB}}$=3 dB. These input values lead to:

$$\begin{aligned} P_{\text{EIRP,dBm}} &= P_{\text{TX, dBm}} + G_{\text{TX, dB}} - A_{\text{Bodyloss, dB}} \\ &= (28 + 1 - 3)\ \text{dBm} \\ &= 26\ \text{dBm}. \end{aligned} \tag{14}$$

For the determination of an IS136-TDMA base station's EISL, again the parameters related to RF processing are kept identical with the GSM case and only the system dependent ones are modified: E_S/N_0=19 dB, G/T=−15.3 dB, r_{Symbol}=24.3 k_{Sym}/s. This results in:

$$\begin{aligned} P_{\text{EISL, dBm}} &= \left(\frac{E_S}{N_0}\right)_{\text{dB}} - \left(\frac{G}{T}\right)_{\text{dB}} + 10\cdot\log_{10}\left(k\cdot r_{\text{Symbol}}\right) \\ &= \left[19-(-15.3)+10\cdot\log_{10}\left(1.38\cdot 10^{-23}\cdot 24.3\cdot 10^{3}\right)\right]\ \text{dBW} \\ &= -120.7\ \text{dBm}. \end{aligned} \tag{15}$$

3.3 UMTS-uplink

With code multiplexed systems the EISL equation (10) has to be modified to account for processing gain associated with those systems. Process gain is derived from the ratio between the chip rate and bit rate:

$$G_P = \frac{r_{\text{chip}}}{r_{\text{bitrate}}}. \tag{16}$$

The energy per symbol is further replaced by the energy per chip:

$$\left(\frac{S}{N}\right)_{\text{Digital}} = \frac{E_c}{N_0}\cdot\frac{r_{\text{chip}}}{B_{\text{Noise}}} = \frac{E_b}{N_0}\cdot\frac{1}{G_P}\cdot\frac{r_{\text{chip}}}{B_{\text{Noise}}}. \tag{17}$$

The equation for the SNR from the RF side is untouched:

$$\left(\frac{S}{N}\right)_{\text{RF}} = \frac{G}{T}\cdot\frac{P_{\text{EISL}}}{k\cdot B_{\text{Noise}}}. \tag{18}$$

Equations (17) and (18) have to be equal:

$$\left(\frac{S}{N}\right)_{\text{RF}} = \left(\frac{S}{N}\right)_{\text{Digital}}$$

$$\frac{G}{T}\cdot\frac{P_{\text{EISL}}}{k\cdot B_{\text{Noise}}} = \frac{E_b}{N_0}\cdot\frac{1}{G_P}\cdot\frac{r_{\text{chip}}}{B_{\text{Noise}}}$$

$$P_{\text{EISL}} = \frac{E_b}{N_0}\cdot\frac{1}{G_P}\cdot\frac{1}{G/T}\cdot\left(k\cdot r_{\text{chip}}\right)$$

$$P_{\text{EISL, dBm}} = \left(\frac{E_b}{N_0}\right)_{\text{dB}} - G_{P,\text{ DB}} - \left(\frac{G}{T}\right)_{\text{dB}} + 10\cdot\log_{10}\left(k\cdot r_{\text{chip}}\right). \quad (19)$$

Looking at above equation it can be seen that the processing gain reduces the EISL and therefore implies an improved sensitivity.

In the following the UMTS mobile's EIRP is determined based on these parameters: Transmit power $P_{\text{TX, dBm}}=21\,\text{dBm}$, antenna gain $G_{\text{TX dBi}}=+1\,\text{dBi}$, body loss $A_{\text{Bodyloss, dB}}=3\,\text{dB}$. This results in:

$$\begin{aligned} P_{\text{EIRP,dBm}} &= P_{\text{TX, dBm}} + G_{\text{TX, dB}} - A_{\text{Bodyloss, dB}} \\ &= (21+1-3)\ \text{dBm} \\ &= 19\,\text{dBm}. \end{aligned} \quad (20)$$

To determine the base station's EISL these values are applied: $E_b/N_0=5\,\text{dB}$, $r_{\text{chip}}=3.84\,\text{Mchip/s}$,

$$G_{P,\text{ dB}} = 10\cdot\log_{10}\left(\frac{3.84\,\text{Mchip/s}}{12.2\,\text{kbit/s}}\right)\text{dB} = 25\,\text{dB},$$

$G/T=-15.3\,\text{dB}$. This results in:

$$\begin{aligned} P_{\text{EISL,dBW}} &= \left(\frac{E_b}{N_0}\right)_{\text{dB}} - G_{P,\text{dB}} - \left(\frac{G}{T}\right)_{\text{dB}} + 10\cdot\log_{10}\left(k\cdot r_{\text{chip}}\right) \\ &= \left[5-25-(-15.3)+10\cdot\log_{10}\left(1.38\cdot 10^{-23}\cdot 3.84\cdot 10^{6}\right)\right]\ \text{dBW}. \end{aligned} \quad (21)$$

Comparing Eq. (21) with Eq. (15) a much lower value for the effective sensitivity with UMTS compared to the effective sensitivity with GSM can be observed. However the UMTS related value has to be adjusted to account for effects specific with code multiplex systems.

3.3.1 Further factors to be considered

In the context of code multiplexed system further factors have to be considered (Holma and Toskala, 2000), for instance "cell breathing", which means that the cell size is a function of network load, meaning that capacity influences coverage.

The first factor that has to be quantified into a link budget as a margin is the interference margin. It accounts for inter- and intracell Interference:

$$M_{\text{Interference, dB}} = 1\ldots3\,\text{dB}\ \ (20\ldots50\%\,\text{Load}). \quad (22)$$

The second margin that has to be considered is the fast fade margin or sometimes also called power control headroom. It accounts for inaccuracies with the power control algorithm:

$$M_{\text{FastFade, dB}} = 2\ldots5\,\text{dB}. \quad (23)$$

Besides margins that degrade the link budget there is also a gain that improves it: Soft handover gain. It reflects the gain by fading mitigation through macro diversity:

$$G_{\text{SoftHo, dB}} = 2\ldots3\,\text{dB}. \quad (24)$$

Now the value for EISL can be adjusted:

$$\begin{aligned} P_{\text{EISL, dBm, adj}} &= P_{\text{EISL, dBm}} + M_{\text{Interference, dB}} + M_{\text{FastFade, dB}} - G_{\text{SoftHO, dB}} \\ &= [-137.5+3+2-3]\,\text{dBm} \\ &= -135.5\,\text{dBm}. \end{aligned} \quad (25)$$

The EISL value gets degraded by high network load. Capacity effects cannot be neglected with analysis of coverage and emission.

3.4 CDMA-uplink

These parameters are assumed for an IS95-CDMA mobile: $P_{\text{TX, dBm}}=23\,\text{dBm}$, $G_{\text{TX, dBi}}=+1\,\text{dBi}$, $A_{\text{Bodyloss, dB}}=380\,\text{dBm}$. They result in an EIRP of:

$$\begin{aligned} P_{\text{EIRP, dBm}} &= P_{\text{TX, dBm}} + G_{\text{TX, dB}} - A_{\text{Bodyloss, dB}} \\ &= (23+1-3)\ \text{dBm} = 21\,\text{dBm}. \end{aligned} \quad (26)$$

As E_b/N_0 is referenced to the channel decoders input also the bit rate at the channel decoders input which is 14.4 kbit/s and thus slightly higher than the service rate of 12.2 kbit/s has to be selected for derivation of the process gain. The calculation of the IS95-CDMA base station's EISL therefore assumes: $G/T=15.3\,\text{dB}$, $E_b/N_0=7\,\text{dB}$,

$$G_{P,\text{ dB}} = 10\cdot\log_{10}\left(\frac{1.2288\,\text{Mchip/s}}{14.4\,\text{kbit/s}}\right)\text{dB} = 10.3\,\text{dB}$$

$r_{\text{chip}}=1.2288\,\text{Mchip/s}$ and results in:

$$\begin{aligned} P_{\text{EISL}} &= (E_b N_0)_{\text{dB}} - G_{P,\text{ dB}} - \left(\frac{G}{T}\right)_{\text{dB}} + 10\cdot\log_{10}\left(k\cdot r_{\text{chip}}\right) \\ &= \left[7-19.3-(-15.3)+10\cdot\log_{10}\left(1.38\cdot 10^{23}\cdot 1.2288\cdot 10^{6}\right)\right] \\ P_{\text{EISL, dBm}} &= -134.7\,\text{dBm}. \end{aligned} \quad (27)$$

3.4.1 Further factors to be considered

Like with the UMTS case further factors accounting for additional margins and gains have to be quantified into the link budget (Yang, 1998):

Interference margin:

$$M_{\text{Interference, dB}} = 3.4\,\text{dB}$$

Fast fade margin, power control headroom:

$$M_{\text{FastFade, dB}} = 2\ldots5\,\text{dB}$$

Soft Handover gain:

$$G_{\text{SoftHO, dB}} = 4\,\text{dB}.$$

The EISL value derived in Eq. (27) can now be adjusted:

$$\begin{aligned} P_{\text{EISL, dBm, adj}} &= P_{\text{EISL, dBm}} + M_{\text{Interference, dB}} + M_{\text{FastFade, dB}} - G_{\text{SoftHO, dB}} \\ &= [-134.7+3.4+2-4]\,\text{dBm} \\ &= -133.3\,\text{dBm}. \end{aligned} \quad (28)$$

Table 1. Typical EIRP and EISL values with wireless uplink and their implications on RF network planning.

	$P_{\mathrm{EIRP,\,dBm}}$	$P_{\mathrm{EIRP,\,dBm,adj}}$	$L_{\mathrm{Path,\,dB}}$	Relative cell radius	Relative cell area	Change in no. of sites
GSM	27	−124.3	151.3	1	1	0
UMTS	19	−135.5	154.5	1.24	1.54	−35%
IS136-TDMA	26	−120.7	146.7	0.73	0.54	+86%
IS95-CDMA	21	−133.3	154.3	1.23	1.5	−33%

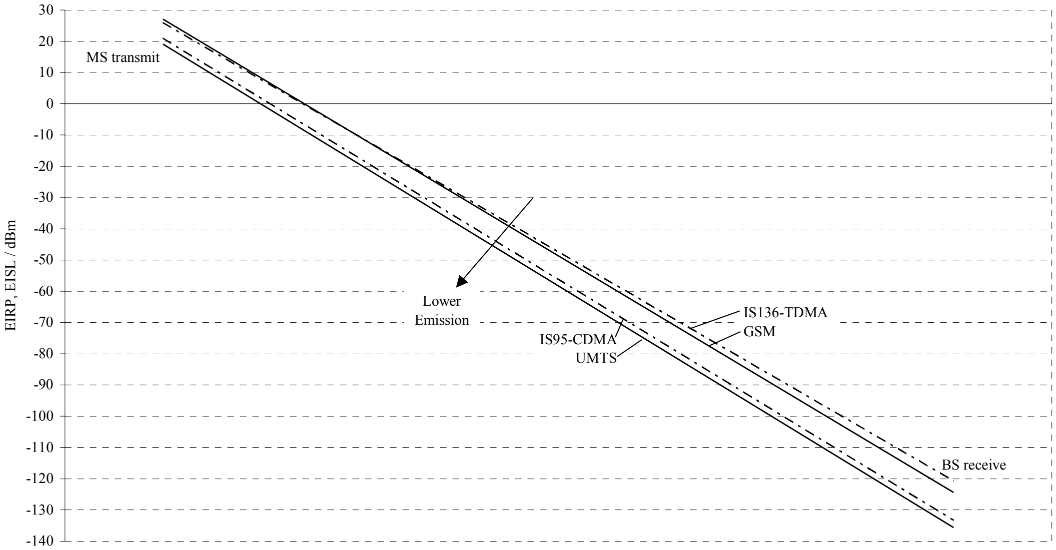

Fig. 4. Link budget comparison of mobile communication standards.

3.5 Comparison and consequences

The results obtained in Sects. 3.1 to 3.4 are summarized in Table 1 and Fig. 4. Table 1 also transfers the differences in link budget into relative changes of cell radius, cell area and number of basestations sites needed. Hereby the GSM link budget is used as a reference point. The relative change in cell radius assumes that the receive power is decaying with distance weighted by an exponent of 3.4, instead of 2 normal with free space.

From Table 1 it can be observed that code multiplexed systems are ahead of time multiplexed ones. They offer a larger cell radius. For covering a larger area around 33% less basestations are needed. As total site costs are about 3 times the cost of a basestation, network operators can obtain huge savings with network deployment. However the figure of −33% assumes a regular cell grid, which is not the case in real scenarios. Therefore practical savings are less. Furthermore it has to be considered that above conclusions are only true if an operator has the choice to deploy either of the standards in the same frequency band. CDMA and UMTS do better by around 3 dB compared to GSM, but if their operating frequency is twice compared to GSM this gain is no longer present as an increase of operating frequency by factor 2 implies about 9 dB more path loss for the same cell radius (see ETSI, 1998). Statements like that UMTS is an inefficient system as it requires much more sites than GSM are therefore questionable. The increase in number of sites is mainly a consequence of the high frequency band not a consequence of the standard. Instead if UMTS would be deployed at 900 MHz, in the same band as GSM, instead of 2100 MHz, sites could be saved. Benefits of low frequency bands in terms of emission and coverage have e.g. been analyzed in a research project funded by the German federal ministry on research and education BMBF (BMBF, 2002).

Figure 4 provides a quick insight into the emission characteristics. The lines shown are just straight connections between data points for mobile EIRP and basestation EISL, with no mapping to the abscissa. The lines are drawn to visualize the slope as the slope of the lines can be interpreted as the maximum path loss supported. IS136-TDMA has a more flat slope than the others and this indicates that it supports less path loss as already shown by Table 1. Furthermore the lower the lines the lower the emission. Systems can offer the same maximum path loss but one may operate at generally lower power levels. This is the case for the code multiplexed systems compared to the time multiplexed ones. They operate generally at 10 dB less power and therefore run at 10 dB less emission. However it has to be stressed that with time multiplexed systems the transmitter isn't on air all the time. With GSM due to 8 timeslots the average emission drops by

9 dB and in IS136-TDMA 3 timeslots are used resulting in a drop by around 5 dB.

In this context it has to be mentioned that the biological effects of pulsed signals are discussed very controversy and that a mathematical rule for weighting the variations of the RF envelope doesn't exist yet.

4 Conclusion

It has been shown that the concept of analyzing the effective usable sensitivity of a receiving system through the metric EISL, describing the effective usable sensitivity at the air interface aside the well known metric EIRP for the effective radiated power, is a powerful tool for doing link budget comparisons between systems of different nature.

EISL is derived from the metric G/T describing the performance of the RF processing part including antenna and RF cabling and $E_{\mathrm{S\,or\,chip}}/N_0$ describing the performance of the digital signal processing part. EISL merges both metrics into a single number together with some system related constants.

EISL shows strong dependence on architectural changes, beam downtilt and seasonal changes.

From the link budget comparisons it is derived that code multiplexed systems run at generally lower emission levels and offer greater cell radius than time multiplexed ones.

It is also observed that the frequency band of operation has a much higher impact on cell size than the differences in the link budgets between the various standards.

The comparisons presented in this article focused on a basic voice service at 12.2 kbit/s. Of course performing comparisons also for data services would be of high interest and that is the scope of ongoing activities in this area.

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