The effects of UWB interference on GSM systems

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***Abstract*— The effects of UWB interference on GSM 900 and GSM 1800 systems are considered for current FCC regulations as well as proposed ETSI emission limits for the criteria of either a 1 dB loss in the SINR or a loss leading to the minimum required SINR at the cell edge. UWB densities are computed for different GSM reuse factors and the results show that no harmful interference is to be expected for GSM 900 systems. In the case of GSM 1800 systems, the proposed ETSI emission limits are found to be offering sufficient protection whereas the current FCC regulations would result in significant interference.**

I. INTRODUCTION

The Ultra-Wideband (UWB) regulatory process in the United States was accompanied by strong opposition against the emission limits, mainly by users of licensed bands, worried about the impact on their existing services. In this paper, we consider the effects on GSM networks that may arise from a mass deployment of UWB devices, using both current FCC regulations [1], [2] as well as proposed ETSI regulations [3].

The negative effects of extra interference on a GSM system can most conveniently be assessed by looking at the SINR at the cell edge, i.e. at the coverage limit. Depending on the level of interference, the loss in SINR will effectively result in a reduced cell coverage radius.

We show a model to compute the aggregate interference from UWB devices for indoor and outdoor scenarios with varying UWB device densities. We consider two different methods to investigate the effect of the interference from UWB devices at the cell edge: a relative loss in SINR and degradation to a target SINR. Based on these considerations we evaluate the maximum permissible UWB transmitter densities.

II. UWB INTERFERENCE MODEL

Most UWB devices are expected to fall into the general category of (mobile) communication devices. This type of application is restricted by the FCC to have its main transmission bands in the range of 3.1 to 10.6 GHz [1], [2]. At those frequencies, the attenuation with distance is significant and therefore, a victim receiver will be most affected by the few nearest UWB transceivers. Given that base stations are generally in elevated locations or otherwise inaccessible, the interference effects will be felt mainly at the mobile terminal. Hence, we will consider the effects on the downlink. In the absence of functional industry standards for UWB, we assume the UWB signal to be spectrally flat in the interfered band.

We shall consider a situation where our victim receiver, the mobile terminal, is located in a plane amongst UWB devices uniformly distributed per unit area, similar to [4]. Consider the victim receiver placed at the centre of two concentric circles with radius r_{min} and r_{max}, respectively, with $r_{min} < r_{max}$. We assume that there is a minimum separation distance between the victim and the nearest UWB device. In the case of an office, for example, it is reasonable to assume that no other radio device will be placed closer than a meter from the victim. We can write the probability density function (pdf) of the UWB transmitters as a function of the radius θ as:

$$pdf(\theta) = \begin{cases} 0 & \theta < r_{min} \text{ and } \theta > r_{max} \\ \frac{2\theta}{r_{max}^2 - r_{min}^2} & \theta \in [r_{min}, r_{max}] \end{cases}$$

The mean interference level is given by the mean received power from all the interfering UWB transmitters, i.e.

$$\begin{aligned} E\{P\} = P_R &= N \int_{\theta=r_{min}}^{r_{max}} P(\theta) \frac{2\theta}{r_{max}^2 - r_{min}^2} d\theta \\ &= 2\pi\rho \int_{\theta=r_{min}}^{r_{max}} P(\theta)\theta d\theta \qquad (1) \end{aligned}$$

where $P(.)$ defines the received signal power of one UWB transmitter at the victim receiver as a function of the distance between them and $\rho = N/[\pi(r_{min}^2 - r_{max}^2)]$ is the density of UWB transmitters per unit area, N is the total number of UWB transmitters. The received power as a function of distance can be approximated by [5]

$$P(d) = P_T \left(\frac{\lambda}{4\pi d}\right)^2 \left(\frac{d_0}{d_0 + d}\right)^2 \qquad (2)$$

where λ is the wavelength of the signal and assumed to correspond to the frequency of the affected GSM service, P_T is the transmit power of the UWB transmitter, d is the distance between the victim and the transmitter and d_0 is the breakpoint distance. For simplicity, we assume that all interfering UWB devices transmit at equal power P_T. The breakpoint distance can be found approximately from [5]

$$d_0 = \frac{12 h_T h_R}{\lambda} \qquad (3)$$

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where h_T and h_R are the heights above ground of the transmitter and the receiver, respectively. Typically, we would assume $h_T = h_R = 1.5$ m. The breakpoint is also a function of the propagation environment and can be set lower to e.g. $d_0 = 10$m to accomodate for indoor environments with stronger attenuation per unit distance. To compute the total interference received by the victim, we combine equations (1) and (2) to obtain

$$\begin{aligned} P_R(r) &= 2\pi\rho P_T d_0^2 \left(\frac{\lambda}{4\pi}\right)^2 \int_{r=r_{min}}^{r_{max}} \frac{1}{r(r+d_0)^2} dr \\ I_{UWB} &= P_R(r)|_{r_{max}\to\infty} \\ &= 2\pi\rho P_T \left(\frac{\lambda}{4\pi}\right)^2 \left[\ln\left(1+\frac{d_0}{r_{min}}\right) - \frac{1}{1+\frac{r_{min}}{d_0}}\right] \end{aligned} \tag{4}$$

where we have integrated by partial fraction and let the outer radius, r_{max}, tend to infinity.

III. GSM CO-CHANNEL INTERFERENCE MODEL

One of the important limiting factors in GSM systems is the level of interference received from other base stations that transmit on the same frequency, the so-called co-channel interference. Using the path loss model introduced in (2), we can write the SINR at the mobile terminal as

$$SINR(r) = \frac{P'_T \left(\frac{\lambda}{4\pi r}\right)^2 \left(\frac{d_0}{d_0+r}\right)^2}{\sum_{i=1}^{M} P'_{T,i} \left(\frac{\lambda}{4\pi d_i}\right)^2 \left(\frac{d_0}{d_0+d_i}\right)^2 + I_{UWB} + n} \tag{5}$$

where P'_T and $P'_{T,i}$ are the transmission power of the primary cell (where the victim mobile is located) and the interfering cells $i = \{1, 2, \ldots, M\}$, respectively. r and d_i are the distances from the primary and the interfering cells to the mobile, and n is the thermal noise. In order to facilitate computation, we assume a standard hexagonal cell cluster model [6] with typically $K \in \{3, 4, 7, 9, 12, 21\}$. For co-channel interference purposes, it is generally sufficient to consider the first tier of neighbouring base stations that transmit on the same frequency as the primary base station. Without cell sectorization, we obtain $M = 6$ interfering cells for the above values of K. The worst case arises when the mobile is located at the edge of its serving cell since the received signal power is at a minimum there. Assuming equal radii and hence transmit power $P'_T = P'_{T,i}$ for all basestations, the cell radius, R, is typically much smaller than the distance to the interfering base stations and we can write $d_i \approx D : D >> R$, where $D = \sqrt{3K}R$ is the distance between basestations. Further, if the cell radius is much larger than the breakpoint distance d_0 (d_0 is around 80m for GSM 900), we can approximate the path loss in (2) by:

$$P(d) \overset{d>>d_0}{\approx} P_T \left(\frac{\lambda}{4\pi d_0}\right)^2 \left(\frac{d_0}{d}\right)^4 \tag{6}$$

In the absence of noise and UWB interference, equation (5) at the cell edge, $r = R$, simplifies to the *carrier-to-interference-ratio* [6]:

$$C/I = \frac{1}{M}(3K)^2 \tag{7}$$

In a noise-free, equal power environment, the C/I is therefore completely determined by the cell cluster structure.

A. Cell radius as a function of the SINR

Since the noise-free considerations above show that the C/I is independent of the transmit power, the effective coverage radius R, for a required SINR, depends only on the interference plus noise component in the SINR. We know that an $SINR_{min} = 9$ dB suffices to maintain a simple voice connection. Using $D = \sqrt{3K}R$, (6), (7) and the equal transmit power assumption, we can now write the SINR in (5) as

$$SINR = C/I \frac{1}{1 + C/I\ \frac{R^4}{\gamma}(I_{UWB} + n)} \tag{8}$$

where $\gamma = P'_T d_0^4 \left(\frac{\lambda}{4\pi d_0}\right)^2$. The thermal noise floor is given from $n = kTB_{rx}$ and k is the Boltzman's constant (1.38×10^{-23} W/Hz/Kelvin), B_{rx} is the receiver bandwidth at ambient temperature K, in degrees Kelvin. For GSM, $B_{rx} = 200kHz$ and temperature $K = 290$ we find a noise floor of $n = -120$dBm.

B. Cell radius as a function of the signal level

As it turns out, the signal level is rather low at the $SINR_{min} = 9$ dB limit and the cell radius is actually limited by the receiver sensitivity. We found that an acceptable minimum signal level at the mobile is normally -90 dBm. Since the mobile receiver cannot distinguish between the useful signal, noise and interference, we can simply define the radius of the cell, R, such that the received signal power is -90 dBm. The total receive power, and therefore the radius, is given by

$$\begin{aligned} P_{tot} &= \frac{\gamma}{R^4}\left[1 + \frac{1}{C/I}\right] + I_{UWB} + n \\ R &= \sqrt[4]{\frac{\gamma\left[1 + \frac{1}{C/I}\right]}{P_{tot} - I_{UWB} - n}} \end{aligned}$$

Calculating the coverage radius based on receiver sensitivity results in an SINR that is strictly greater than the minimum 9 dB required. Hence, we can compute the maximum permissible UWB Interference that will lead to a *target SINR* at the cell edge, i.e.

$$I_{UWB} = \frac{\gamma}{R^4}\left[\frac{C/I - SINR_{trgt}}{SINR_{trgt}\ C/I}\right] - n$$

Together with equation (4) we can therefore obtain the density of UWB transmitters, ρ, that can be tolerated by the system for a given $SINR_{trgt}$.

IV. UWB INTERFERENCE TO GSM 900

We will now consider the application of the results of the previous sections to GSM 900 systems, using the FCC emission limits and a proposed ETSI emission mask [3]. Since UWB industry standards are yet to be defined, we assume the UWB signal to be spectrally flat and transmitting at the maximum power permitted in the band of the victim receiver, according to the FCC/ETSI emission masks.

We consider two different scenarios: a relative degradation in SINR of 1 dB and the degradation to an absolute, minimum target SINR. A relative SINR decrease is only relevant when the reuse factor is small or, more generally, the level of interference is high, i.e. in the low SINR regime. In this case, the loss of 1 dB is significant since little additional loss in SINR can be tolerated. On the other hand, for a large reuse factor, the initial SINR will be well above the minimum so that a loss of 1 dB can be considered insignificant. In these cases, it is more meaningful to consider the maximum UWB transmitter density that will achieve a minimum signal quality, i.e. SINR. To assess the obtained densities, we consider that a minimum of $\rho = 0.2$ always-on (i.e. with a unity activity factor) UWB transmitters per m^2 need to be tolerable by the system in order to conclude that the interference is not harmful. We emphasize that actual activity factors are likely to be substantially lower, meaning that a potentially much larger number of physical devices will cause the same level of interference as the unity activity factor devices considered in this study.

A. UWB interference using the FCC mask

The FCC defines different classes of UWB devices [1], [2]. Here, we will only consider the class of communication and measurement systems as they are forecast to represent ca. 98% of the market. These UWB devices must have their transmission band in the range from 3.1 GHz to 10.6 GHz. Hence, the GSM 900 band is clearly outside the main band and will therefore only receive out-of-band interference. For both indoor and outdoor applications, the maximum emission power spectral density is limited to -75 dBm/MHz in the 900 MHz bands of GSM. In a GSM 900 channel of 200 kHz, this corresponds to a maximum UWB transmit power of -82 dBm. The radius of the inner circle defining the minimum distance to the closest interferer is set to $r_{min} = 1$m.

In Figure 1, the UWB transmitter densities leading to a 1 dB degradation of the SINR and a reduction to an absolute SINR of 9dB at the cell edge are shown when using the FCC emission mask. The difference between the outdoor and indoor environments is the setting of the breakpoint: For the indoor environment, the breakpoint has been set to $d_0 = 10$m, whereas for the outdoor environment, the breakpoint is set according to (3). From Figure 1 we can see that the indoor environment can support higher densities than the outdoor environment. This is due to the stronger attenuation of the interfering UWB transmitters with distance. We also remark that the density level decreases with the reuse factor for 1dB relative loss, which may give the mistaken impression that the system with a higher reuse factor is more susceptible to extra interference. Although this appears somewhat counter-intuitive, this is due to the fact that the received *useful* signal remains about constant for various reuse factors while the noise and interference term decreases. Hence, for larger reuse factors, a 1 dB decrease occurs at a much higher SINR through a much smaller *absolute* increase in the interference term. Recall from equation (7) that a) $C/I \propto K^2$ and b) the SINR in equation (8) is limited only by the interference plus noise term such that

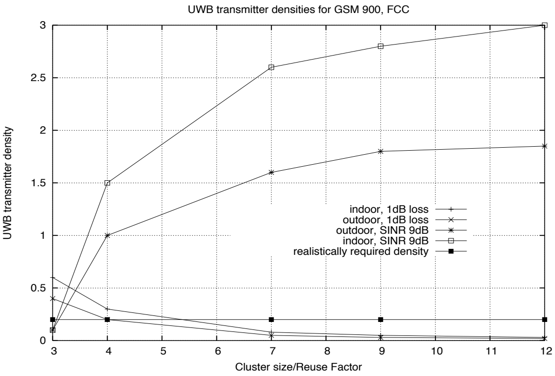

Fig. 1. The densities of UWB transmitters causing a 1 dB drop in SINRat the cell edge (GSM 900, FCC)

$$SINR \propto \frac{1}{1/K^2 + c} \overset{K\to\infty}{=} \frac{1}{c}$$

where $c = \frac{R^4}{\gamma}(I_{UWB} + n)$. If we consider the case of a degradation to the minimum, $SINR_{trgt} = 9$ dB,we see that the supported densities are largely above the required 0.2 transmitters/m^2, except for Reuse factor $K = 3$. In this case, the SINR without UWB interference was already less than 1 dB above $SINR_{trgt}$.

Since the supported densities are greater than 0.2 transmitters/m^2 in the low SINR regime ($K = 3, 4$) for a 1 dB drop in the SINR and largely above in the high SINR regime ($K > 4$), we conclude that it is unlikely that the application of the FCC spectral mask would lead to harmful interference to the GSM 900 system at the cell border.

B. UWB interference using the proposed ETSI mask

The main difference in the ETSI proposal from the FCC regulations is the more stringent out-of-band limits that apply. The approach used to evaluate the supported densities is equivalent to the one given above for the FCC regulations. From [3], we find that the UWB interference power in a GSM channel of 200 kHz is limited to a maximum of -105 dBm.

Using the same parameters as in the last section, we find the results in Figure 2 for a 1 dB degradation in SINR and for a degradation down to $SINR_{trgt} = 9$ dB, respectively. From those results it is immediately clear that the densities supported by the proposed ETSI limits are enormous and, therefore, the effect of UWB interference on GSM 900 systems is completely negligible for realistic densities of ≤ 0.2 UWB transmitters/m^2.

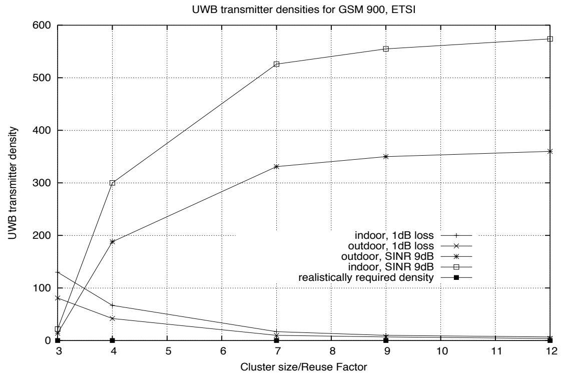

Fig. 2. The densities of UWB transmitters causing a 1 dB drop in SINR at the cell edge (GSM 900, ETSI)

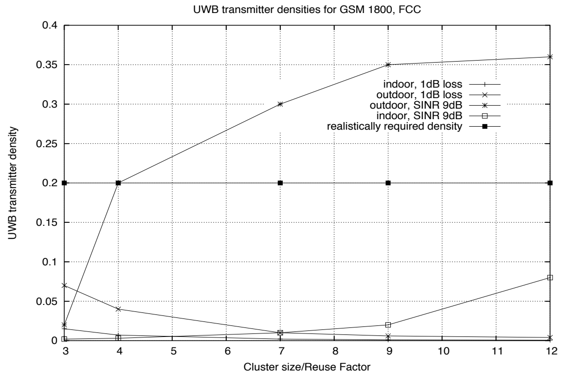

Fig. 3. The densities of UWB transmitters causing a 1 dB drop in SINR at the cell edge (GSM 1800, FCC)

V. UWB INTERFERENCE TO GSM 1800

The only difference between GSM 1800 and GSM 900 is the change of the transmission frequency, leading primarily to a greater attenuation with distance. While GSM 1800 is still out of the main UWB transmission band, the fact that it is substantially closer means that the UWB interference power is increased. The other parameters are the same as for the GSM 900 calculations above.

A. UWB Interference using the FCC mask - GSM 1800

Note that in the case of the FCC limits, two different limits exist for outdoor and indoor applications [1], [2]. These result in -60dBm and -70dBm UWB interference power for indoor and outdoor applications, respectively, in a 200 kHz GSM channel. In Figure 3, the results for a 1 dB loss in SINR and for $SINR_{trgt} = 9$ dB are shown. We can see that even for low reuse factors, $K = 3, 4$, the permissible densities are clearly below the desired 0.2 UWB transmitters/m^2 for the 1 dB loss in SINR. In the case where the target SINR is considered the supported transmitter densities are somewhat higher but still rather low, even for high reuse factors and SINR. In particular, the extra transmission power indoors is responsible for very low acceptable transmitter densities in this environment. Hence, the FCC emission limits are likely to result in harmful interference for GSM 1800 at the cell boundary. The outdoor case seems borderline sufficient while the indoor case is clearly insufficient.

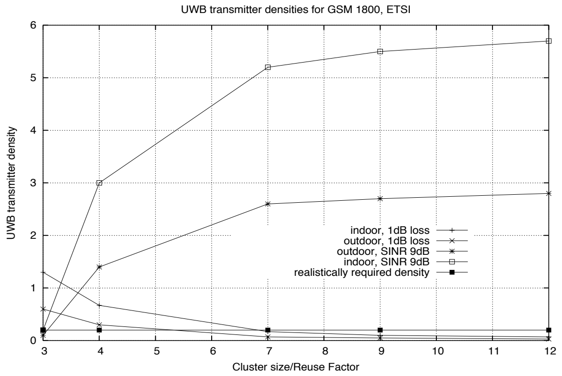

Fig. 4. The densities of UWB transmitters causing a 1 dB drop in SINR at the cell edge (GSM 1800, ETSI)

B. UWB Interference using the proposed ETSI mask - GSM 1800

The ETSI mask does not distinguish between indoor and outdoor applications [3]. In the 1800 MHz band, the resulting UWB interference power for a 200 kHz GSM channel is limited to -79 dBm. The maximum UWB device densities for a 1 dB degradation in SINR and a degradation to the target SINR of 9 dB are shown in Figure 4. As can be seen, the resulting densities for the 1 dB loss in SINR are clearly sufficient to accommodate realistic device densities, i.e. ¿0.2 transmitters/m^2. Equally, the densities for the higher reuse factors and hence the high SINR cases, are well above the required minimum density. In summary, it can be stated that no significant interference is likely to GSM 1800 systems from UWB systems employing the ETSI spectral mask.

VI. CONCLUSIONS

This paper considers the effects on GSM from UWB systems, using either the FCC or proposed ETSI emission limits. It was shown that no harmful interference is to be expected for GSM 900 systems. In the case of GSM 1800 systems, the protection afforded by the FCC regulations appears insufficient at the cell border whereas the proposed ETSI limits avoid any significant interference.

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