Minimising the Electromagnetic Exposure at Hot-Spot Areas using Hybrid (DVB-H/UMTS) Networks

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Abstract—A hybrid mobile communication network as considered in this paper consists of a point-to-point network (UMTS) and a point-to-multipoint network (DVB-H). The benefit of combining these two networks is an optimised transfer of data by collecting several user requests for a single response via the broadcast network. Thus, capacity can be saved, UMTS cells can be unloaded and the mean response time of the system can be reduced. Besides these advantages, hybrid networks can be applied to decrease electromagnetic exposure at hot-spots. This problem will be analysed in this paper. Therefore, a scenario has been developed which includes a hot-spot area. Furthermore, this paper includes the definition of a criterion to estimate the benefit of reducing the electromagnetic exposure using a hybrid network. The results are shown in an example scenario.

I. INTRODUCTION

In this context, a hybrid mobile communication network consists of a point-to-point (unicast) system and a point-to-multipoint (broadcast) system. The benefits of both systems will be combined in order to optimise transfer of data. On the one hand bidirectional point-to-point channels are used for individual services. On the other hand, a unidirectional broadcast channel offers high data rates for the downlink. Requests of the same content can be combined to serve all users by only one transmission at the same time instead of individual transmissions. Thus, necessary capacity can be saved.

The herein described hybrid networks combine the mobile communication network UMTS (Universal Mobile Telecommunications System) and the broadcast system DVB-H (Digital Video Broadcasting - Handheld). DVB-H is a broadcast system based on DVB-T (Digital Video Broadcasting - Terrestrial). It is optimised for small devices such as mobile phones by using time slicing for less power consumption and an additional forward error correction (FEC) providing more robust signals [1], [2].

Besides reducing the necessary capacity, other advantages of hybrid networks are the reduction of the mean response time of the system and unloading the UMTS network by offering additional downlink capacity [3], [4].

In this paper it is investigated whether hybrid networks can be used to reduce electromagnetic exposure. Electromagnetic waves may have an influence on the human body, e.g. thermal influences on the human tissue [5]. The electromagnetic exposure of radio communications systems is seen critical by the public. Thus, reducing the electromagnetic exposure of radio systems is an important issue.

A single UMTS network will be compared to a hybrid network, consisting of UMTS and DVB-H. Both network types are deployed in order to serve the same amount of user requests. Deploying a hybrid network consisting of UMTS and an additional DVB-H network can provide high data rates at the downlink. Especially at hot-spot areas, where many users are located at a close place, a broadcast transmitter could replace several Node-B’s, which has an impact on the electromagnetic exposure.

This paper is organised as follows: In Section II the services, the reference UMTS network and the two different network types, the enhanced UMTS network and the hybrid network, are described. Section III specifies the criterion which is used to measure the amount of electromagnetic exposure. This criterion will be used in Section IV to compare the different networks.

II. SCENARIO

In order to investigate both network types on electromagnetic exposure, a scenario has been developed which also includes hot-spot areas. The scenario contains assumptions on user behaviour and geographical user distribution. Different service classes are described, which are offered to be transmitted by each type of network. Considering the user information, the UMTS reference network has been developed, including Node-B positions and transmitting power. Furthermore, the power level predictions are based on building data and topographical data.

For the scenario area, the city of Hannover was selected. The area has a size of 15 km × 12 km and a resolution of 50 m × 50 m per pixel. In order to show the benefit by reducing electromagnetic exposure in hot-spot areas, the football stadium of Hannover was selected, which is one of the FIFA football world championship arenas in Germany 2006. Especially during those events, thousands of spectators, inside or around the stadium, are expected to consume video content using their mobile terminals. Regarding this extreme amount of requested data, it is expected that the UMTS network will not be able to fulfil all user requests. Therefore, the UMTS network has to be enhanced by additional Node-B’s, alternatively an additional DVB-H network can be used to strengthen the downlink.
A. Service Scenario

Two types of services are considered. On the one hand, typical services, such as voice telephony, will be transmitted solely by the UMTS network. On the other hand, high data rate download services, such as video, are considered to be transmitted either by the UMTS or by the hybrid network.

The typical UMTS services which can be requested by the users are based on the scenario of the IST-MOMENTUM project [6]. Assumptions on the user behaviour are given for each service, such as voice and video telephony, web-browsing, streaming multimedia, multimedia messaging service, e-mail, location based services and file download. The user behaviour, i.e. call attempt rates, depends on the location of the user. Thus, an operational environment map is used which specifies different usage classes, e.g. central business district, suburban or rural areas [6]. In addition, a population density map is necessary which specifies the geographical distribution and the density of the users.

Using these input data, maps are calculated providing the busy hour call attempts (BHCA) for each service. The BHCA values represent call attempt rates during the most active hour. The BHCA maps, indicating the geographical dependent user behaviour for each separate UMTS service, were used for designing the UMTS reference network.

The above mentioned eight service classes are typical UMTS services. In order to describe the football-video service, an additional class is included. Content of this service can be transferred either by the UMTS network in a point-to-point mode or by the DVB-H network in broadcast mode.

B. UMTS Reference Network

The UMTS reference network has been designed for fulfilling the user requests for the eight typical UMTS services. The design process is based on snapshots where users are randomly generated at the scenario area. Thus, a random value generator determining the active users has been developed. This generator requires the mean number of users for each position of the scenario. These values are generated using the BHCA maps and the mean holding time of each service. The users of each snapshot are assigned to Node-B’s. Therefore, potential Node-B locations were selected and for each one a signal level propagation was calculated. A propagation model for dense urban areas [7] was selected, which uses building data. For the UMTS network, a macro cell structure is assumed.

The same configuration consisting of sectorisation, tilt and antenna type is applied for each Node-B.

In order to assign users to a serving Node-B, they are randomly selected from the snapshot. The Node-B is selected which is the best server for the user in terms of receiving power. A user will be assigned to the selected Node-B, if the uplink link budget restriction is satisfied. This means that the maximum uplink power of the terminal (21 dBm) is sufficient to reach the Node-B. Other criteria are the uplink and downlink load factor according to [8]. If these values meet a fixed threshold, the user will be assigned to the Node-B. Otherwise the next best server Node-B will be selected. If the user cannot be assigned to any Node-B, it will be marked as rejected. The number of rejected users is a measure for the quality of the UMTS network.

At the beginning of the network design process more potential Node-B’s were provided than probably necessary. Their positions were selected on roof tops. After the assignment process those Node-B’s were removed which were not or very rarely used. The necessary UMTS transmitting power was adapted considering the necessary connections. Figure 1 shows the achieved UMTS reference network structure and the best server receiving level. About 100 snapshots were used for the assignment process. The fully occupied stadium is covered with three Node-B’s.

C. Enhanced UMTS Network

The UMTS reference network was designed to serve the eight typical UMTS services. For the hot-spot area stadium a video service is assumed, offering highlights of the current and also other football matches, as well as news content. The video content is transferred by video streams with a data rate of 384 kbps and a resolution of $352 \times 288$ pixels according to CIF (common intermediate format) [9]. Adding the new video service, it is expected to produce a heavy traffic mix which cannot be handled by the UMTS reference network.

Figure 2 shows an assignment result of a representative snapshot including video users. Firstly it can be seen that a large number of users (about 65 of 389 total users) could not be assigned to a Node-B. Among these, about 30 voice users were rejected, caused by the random assignment procedure. Furthermore, many users at the stadium are connected to Node-B’s far away. This indicates that the Node-B’s inside the stadium are totally occupied. Furthermore, low signal quality may occur for these connections.

In order to serve the complete service mix, the capacity of the UMTS network has to be enhanced. This is done by including additional Node-B’s. Simulations have shown that six new Node-B’s with three sectors each are sufficient. In Figure 3 the enhanced UMTS network is shown. With the additional Node-B’s it is possible to serve the users, also those who consume the video service.

D. Hybrid Network Architecture

Instead of enhancing the UMTS reference network by additional Node-B’s, a DVB-H network could be deployed in order to form a hybrid network. DVB-H offers broadcast

![Fig. 1. UMTS reference network structure and best server receiving power level](image-url)
channels with high downlink data rates. Therefore, services requiring high data rates at the downlink, such as the video service, are suitable to be transmitted by the DVB-H network.

In a hybrid network, the video service can either be transmitted by the UMTS network or by the DVB-H network depending on the load balancing strategy. In order to optimise data transfer at the hybrid network, a load balancing algorithm will be applied [10]. This method analyses the popularity of content, user request rates and the load of the UMTS cells to decide the way of transmission. The popularity of content describes the frequency of user requests for the appropriate content. The more often a certain content is requested, the higher its popularity is. A possible distribution of popularity for video content is the Zipf distribution (Equation 1). In [11] it is shown that the Zipf distribution is suitable for the popularity distribution of video contents such as the football-video service.

\[
P(i) = \frac{1}{\Omega i^\alpha} \quad \text{and} \quad \Omega = \sum_{j=1}^{C} \frac{1}{j^\alpha} \quad 1 \leq i \leq C; \quad i, C \in \mathbb{N}; \quad \alpha \geq 0
\]  

Equation 1

\( P(i) \) gives the probability of the usage of channel \( i \). The popularity function \( P(i) \) depends on the number of offered channels \( C \) and the shape parameter \( \alpha \). With \( \alpha \) equal to zero, all channels have the same popularity. With an increasing \( \alpha \), the popularity of a small number of channels increases whereas the popularity of the other channels decreases.

For the video service it is assumed that nine different video streams are offered using a data rate of 384 kbps each. A Zipf shape value \( \alpha = 1.1 \) is assumed. This indicates a dominating stream of about 38.5% proportion of all user requests. This stream can be seen as a highlight video of the current match. The other streams have a fraction of 18%, 11.5%, 8.4%, 6.5%, 5.4%, 4.5%, 3.9% and 3.3% respectively.

The mean number of users of the video service at the stadium over all snapshots is 87 users. This leads to a distribution of about 34 users for the dominating stream and about 3 users for the stream with the lowest popularity. According to [10] it is assumed that all streams will be transmitted by the broadcast network due to sufficing popularity. Furthermore, the UMTS network is highly loaded, thus, the remaining data rate in each cell is limited.

In order to transmit nine different video streams having a data rate of 384 kbps each, a total capacity of about 3.5 Mbps is necessary. Therefore, one DVB-H cell having the DVB-H mode QPSK with code rate 1/2 and MPE-FEC 3/4 offering a data rate of 3.7 Mbps is sufficient.

Table I shows the assumed DVB-H configuration. The link budget includes the necessary carrier-to-noise ratio depending on the DVB-H mode, i.e. QPSK, and a fading margin. The minimum receiving power level results to \( P_{\text{min}} = -74.95 \, \text{dBm} \) which limits the coverage area.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>500 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>8 MHz</td>
</tr>
<tr>
<td>Noise Floor Level</td>
<td>-105.2 dBm</td>
</tr>
<tr>
<td>Receiver Noise Figure</td>
<td>5 dB</td>
</tr>
<tr>
<td>Carrier-to-Noise</td>
<td>9.6 dB (assuming the DVB-H mode 8K, QPSK, Viterbi code rate 1/2, MPE-FEC code rate 3/4)</td>
</tr>
<tr>
<td>Receiver Antenna Gain</td>
<td>-9.65 dBi</td>
</tr>
<tr>
<td>Fading Margin</td>
<td>6 dB (assuming a standard deviation of ( \sigma = 6 ) dB and a coverage probability of 84%)</td>
</tr>
<tr>
<td>Minimum Receiving Level</td>
<td>( P_{\text{min}} = -74.95 , \text{dBm} )</td>
</tr>
</tbody>
</table>

Table I

A circular cell for covering the stadium is assumed using a isotropical antenna type. Due to the very limited area of the hot-spot, the size of the target area to be covered has a radius of 400 m. Regarding the propagation effects an ideal circular cell cannot be reached. The target is to cover the stadium also with indoor coverage and the near surrounding. It is assumed, that for the buildings close to the stadium indoor reception is not required. Due to the propagation effects a circular cell cannot be reached. Thus, the target area will be covered with a threshold of 95% of the total area size. The
antenna height is set to 30 m at the north side of the stadium. Considering the minimum receiving level calculated in Table I, a transmitting power (EIRP) of 35 dBm is necessary. Figure 4 shows the coverage area of the hot-spot. The stadium with indoor reception and its surrounding are covered.

### III. EXPOSURE ESTIMATION

In the section before, two network types were described, on the one hand a single UMTS network with the enhanced UMTS network structure described in Section II-C. On the other hand the hybrid network consisting of the UMTS reference network and one DVB-H transmitter covering the hot-spot area is considered. Both network types have to be compared in terms of the arising electromagnetic exposure.

To avoid too high exposure values, reference levels for the electromagnetic exposure are standardised. These thresholds are based on the general public exposure values in [5]. Table II specifies the reference levels for different frequency ranges.

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Reference level of electromagnetic field strength $E_{L,f}$ $[V/m]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-400 MHz</td>
<td>28</td>
</tr>
<tr>
<td>400-2000 MHz</td>
<td>$1.375 \cdot \sqrt{f}$</td>
</tr>
<tr>
<td>2-300 GHz</td>
<td>61</td>
</tr>
</tbody>
</table>

**TABLE II**

**REFERENCE LEVEL FOR GENERAL PUBLIC EXPOSURE** [5]

The propagation model gives the predicted power maps as power level values. Thus, these values have to be transformed into the necessary electromagnetic field strength values. Equation 2 is used to transform the receiving power at the terminal depending on the frequency $f$ and the antenna gain of the terminal $G_e$.

$$E[dB\mu V/m] = P_e[dBm] + 77.2 + 20\log f[MHz] - G_e[dB]$$

(2)

In order to enable the comparison of the different network types, a criterion has to be applied which also considers the different transmitting frequencies of the hybrid network. The exposure limit at a certain position of the area is met if the constraint of Equation 3 is satisfied [5, eq. 9]. The field strength value of each frequency part is related to the frequency dependent reference level specified in Table II. The sum of all ratios should not exceed the limit of 1.

$$\sum_{f=100kHz}^{1MHz} \left( \frac{E_f}{87/\sqrt{f}} \right)^2 + \sum_{f>1MHz}^{300GHz} \left( \frac{E_f}{E_{L,f}} \right)^2 \leq 1$$

(3)

The networks considered in this work are UMTS at 2140 MHz and DVB-H at 500 MHz. As an assumption, these two frequencies are solely considered in order to estimate differences between the two network types in terms of electromagnetic exposure.

In Equation 4 the exposure ratio $U$ is defined. The field strength value of a network is related to the reference level at the appropriate frequency. Considering the single UMTS network, the 500 MHz part does of course not exist.

$$U = \left( \frac{E_{2140MHz}}{E_{L,2140MHz}} \right)^2 + \left( \frac{E_{500MHz}}{E_{L,500MHz}} \right)^2$$

(4)

The exposure ratio will be calculated for each point of the selected area of the scenario using Equation 4 resulting to an exposure ratio matrix. Two results are interesting for comparison, the maximum exposure ratio $\hat{U}$ and the mean exposure ratio $\overline{U}$, which will be obtained from the exposure ratio matrix. The constraint of $\hat{U} \leq 1$ as the upper limit has to be met.

The benefit of the hybrid network is estimated with the gain value specified in Equation 5.

$$G = \frac{U_{UMTS}}{U_{hybrid}}$$

(5)

The exposure ratio value of the single UMTS network is compared to the exposure value of the hybrid network. Both cases, mean and maximum exposure ratio values, will be evaluated. A gain value of $G = 1$ indicates that a hybrid network does not bring a benefit in terms of reducing electromagnetic exposure. A gain value larger than 1 stands for the degree of reduction of electromagnetic exposure. A gain value smaller than one indicates that a hybrid network is not suitable in order to decrease electromagnetic exposure.

### IV. SIMULATION RESULTS

The two network types, the enhanced UMTS network described in Section II-C and the hybrid network described in Section II-D, are compared in terms of electromagnetic exposure. The gain value defined in Equation 5 is used to estimate the benefit of the hybrid network in terms of decreasing electromagnetic exposure.

The calculation of the exposure ratio $U$, especially the mean value $\overline{U}$, is heavily dependent on the selected area. Due to the small size of the hot-spot and the small size of the coverage area, an area around the stadium of 1000 m $\times$ 1000 m was selected.

Figure 5 shows the exposure ratio maps for the enhanced UMTS network. In Figure 6 the exposure ratio map of the hybrid network is depicted. It is obvious that the single UMTS network causes a higher exposure ratio, compared to the hybrid network, especially in immediate vicinity of the stadium.
In Table III the values for the exposure rate and the gain value are given. Using the mean exposure rate value $\hat{U}$, a gain of $G = 1.84$ is reached. The large saving of exposure is ascribed to the replacement of six Node-B’s by only one DVB-H transmitter. The gain value using the maximum exposure ratio $\bar{U}$ only reaches $G = 1.36$. This can be described by the close positioning of the DVB-H transmitter at the Node-B.

The simulations have shown that the exposure also depends on the UMTS network cell structure, i.e. on the used power of the common pilot channel (CPICH). For the reference UMTS network the same pilot power of 33 dBm is used. Changing the pilot power may cause problems during the planning process and particulary in operating UMTS networks, e.g. due to the decrease of the soft handover regions between cells. Nevertheless, the stadium can be seen as a zoned area, where lower pilot power levels could be applied without a significant influence of the surrounding cells. In Table III the results are shown, in case the pilot power for the Node-B’s at the stadium in the enhanced UMTS network is reduced by half. It is assumed that the pilot power in the hybrid network is not changed. The exposure ratio of the single UMTS network is decreased. But the gain value for the mean exposure ratio of $G = 1.26$ is still larger than 1 and the hybrid network brings still a benefit in terms of saving exposure.

### Table III

<table>
<thead>
<tr>
<th>Pilot Power</th>
<th>Exposure Ratio UMTS Network</th>
<th>Hybrid Network</th>
<th>Gain G</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 dBm</td>
<td>$\hat{U}$ [%]</td>
<td>$6.21 \cdot 10^{-4}$</td>
<td>$3.37 \cdot 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>$\bar{U}$ [%]</td>
<td>0.8349</td>
<td>0.6115</td>
</tr>
<tr>
<td>30 dBm</td>
<td>$\hat{U}$ [%]</td>
<td>$4.24 \cdot 10^{-4}$</td>
<td>$3.37 \cdot 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>$\bar{U}$ [%]</td>
<td>0.6306</td>
<td>0.6115</td>
</tr>
</tbody>
</table>

### V. Conclusion

Reducing electromagnetic exposure of radio systems is an important issue. In this paper, it is shown that a hybrid network consisting of DVB-H and UMTS can be beneficial in terms of electromagnetic exposure especially at hot-spot areas. The additional high data rate downlink channel offered by the DVB-H network can be used for a more efficient transmission of video services. Thus, capacity can be saved compared to a single UMTS network. This benefit is used to reduce the electromagnetic exposure, because less Node-B’s are necessary to serve the same amount of user requests. A gain value was defined, describing the benefit of the hybrid network compared to a single UMTS network. At the hot-spot stadium a gain value of $G = 1.84$ for reducing the mean exposure ratio was achieved.

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