Radio Network Planning of DVB-H/UMTS Hybrid Mobile Communication Networks

Peter Unger, Thomas Kürner
Institut für Nachrichtentechnik (IfN)
Technische Universität Braunschweig
Braunschweig, Germany
Email: {Unger,Kuerner}@ifn.ing.tu-bs.de

***Abstract*— The benefit of hybrid mobile communication networks combining point-to-point and point-to-multipoint systems should be an optimized transfer of data for both providers and customers. Optimized network planning is a non-trivial task even for a single network. Hence, planning and optimization of hybrid networks implicate great challenges. For these issues realistic traffic estimations are required. Therefore, a scenario has been developed based on the public reference scenario of Berlin from the IST-MOMENTUM project. A method for designing a DVB-H network architecture including transmitter position and cell size is introduced. Furthermore, the necessary transmitting power is estimated. The benefit of a hybrid network is introduced and shown in an example.**

I. INTRODUCTION

The multimedia service demand of mobile users increases more and more. Many of these services will be asymmetric and interactive, whereas users receive large amounts of data. Therefore, mobile broadband access using interactive channels has to be supplied.

Concerning 3G cellular networks, limitation problems still occur, if many users are consuming high data rate services such as video. Especially the transmission of the same data which is consumed by many users at the same time and at a similar place would allocate a significant amount of resources. Broadcast systems would then be more suitable to serve these users. Broadcast networks provide broadband access serving many users simultaneously but do not support interactivity.

The combination of unicast (bidirectional point-to-point) and broadcast (unidirectional point-to-multipoint) networks to form a hybrid network could provide both broadband access to many users and individual interactive channels. In this paper, we are focusing on hybrid mobile communication networks, including unicast and broadcast delivery systems, UMTS (Universal Mobile Telecommunications System) and DVB-H (Digital Video Broadcasting - Handheld), respectively.

DVB-H is a broadcast system based on DVB-T (Digital Video Broadcasting - Terrestrial). It is optimized 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].

In this paper, for the DVB-H broadcast system a cellular approach is applied, whereas the cell coverage may range from localized areas to vast regional networks. The herein described method shall give a first approach to automatic network planning for hybrid networks. Primarily, DVB-H cells are to be placed in an area of a realistic scenario. After this, transmitting power according to transmitter height has to be estimated. Since capacity is one of the key parameters for network planning, the scenarios are based on data rates necessary for transmitting the requested services. In this case, those scenarios are considered where potential DVB-H users demand typical broadcast content in the form of video data. In this work, the main aspect is to compare the required capacity of a single unicast network and the capacity of a hybrid network providing unicast and broadcast technologies.

For our investigations on hybrid network architectures we initially assume ideal propagation of DVB-H signals. Therefore, circular broadcast cells are used for estimating their position and size. In order to estimate the necessary transmitting power of each DVB-H transmitter, a propagation model is applied to adjust the predicted coverage to the assumed circular area. The developed DVB-H network architecture is then used to evaluate the benefit for a UMTS network in terms of unloading UMTS cells.

This paper is organized as follows: Section II describes a scenario which is used for evaluating user data rates. Section III specifies how to determine size and position of DVB-H cells. Section IV describes a method on how to evaluate the necessary transmitting power and shows the predicted coverage area of the selected DVB-H network. Section V shows the benefits for a UMTS network by introducing a broadcast DVB-H network.

II. SCENARIO FOR HYBRID NETWORKS

For optimized network design information of user behavior, geographical distribution of users and data rates of each offered service are required. The IST-MOMENTUM project provides a public reference scenario of Berlin [3]. The scenario data include characterization of services, user activity and user distribution, and operational environments for a UMTS reference network. Furthermore, an enhanced scenario has been defined describing user distribution and user behavior for DVB-H services. The following passages give a short description of these scenarios.

A. UMTS Scenario of Berlin

The MOMENTUM public reference scenario of Berlin provides several grid maps for the city center of Berlin with a resolution of 50 m x 50 m per pixel in an area of 7.5 km x 7.5 km. Information is given per selected services such as speech and video telephony, web-browsing, streaming multimedia, location based services, multimedia services, e-mail and file download [4]. For each service, average load (AL) and busy hour call attempts (BHCA) per pixel are given.

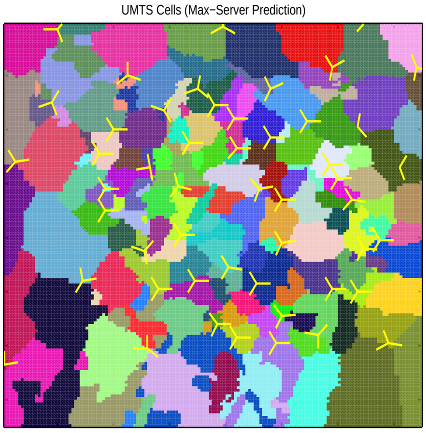

Fig. 1: *UMTS Cells Determined with a Best-Server Prediction and a Node-B Base Station Structure (Size of Area 7.5 km x 7.5 km)*

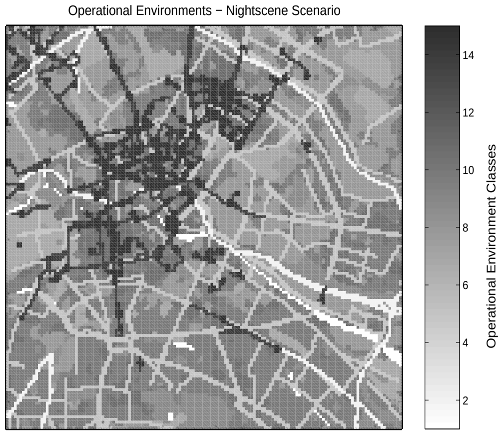

Fig. 2: *Operational Environment Map for the Nightscene Scenario*

Additionally, an operational environment map is specified which segments the area into different classes of user behavior.

The IST-MOMENTUM project offers a UMTS network architecture including position and height of Node-B's, number of sectors and antenna types. A cell structure was calculated using a best-server prediction with an extended Okumura-Hata model [5]. After smoothing cell boarders a cell structure as shown in Figure 1 was achieved.

B. *Enhanced Scenarios for DVB-H*

The MOMENTUM reference scenario was enhanced by including assumptions regarding user behavior and user distribution of the DVB-H service usage. In [6] four scenarios providing different DVB-H usage characteristics are presented. In this paper, the so-called Nightscene scenario was selected as an example. The Nightscene scenario is defined as locations of celebrative night events and important routes toward the locations. Offered content at these locations is expected to be a kind of advice where to move, by means of live videos advertising each location.

Figure 2 shows the operational environment map for the Nightscene scenario. The first eleven operational environment class numbers are equal to the MOMENTUM reference scenario. Three additional classes are included to specify the new user behavior classes for DVB-H services. The darker parts (class numbers twelve to fourteen) show the main areas of usage of DVB-H video content. These areas are distributed in a wide part of the scenario map based on realistic positions of locations.

In this context, several channels of different video content are considered. In order to transmit video content via DVB-H a constant data rate of 384 kbps per channel is required, according to CIF (common intermediate format) with a resolution of 360*288 pixels [7]. As described in Section III, video content may also be transmitted by the unicast network. In this case, this content will be transferred by a UMTS bearer service with a data rate of 384 kbps.

Considering the quantum of services of the enhanced scenario it is expected to produce a heavy traffic mix which possibly cannot be handled by the single UMTS network.

III. HYBRID NETWORK DESIGN

This section focuses on analyzing the hybrid transfer of data by offering services either via a unicast or a broadcast network. Typical unicast services (e.g. voice) are expected to be transferred solely by unicast. As an assumption, requested DVB-H services will be transferred either by unicast or by broadcast depending on the number of users. By using hybrid unicast/broadcast networks, a benefit is expected if several users consume the same service at the same time. Data rate can be saved if these users are served by a single transmission of data by the broadcast system.

A. *Gain of Hybrid Networks*

In order to estimate the benefit of hybrid networks, the gain parameter G (Equation 1) is defined. The required capacity of a single unicast system is compared to the capacity of a hybrid system using both unicast and broadcast technologies. In both cases all types of services are considered. More detailed investigations of multicast gains are performed in [8].

$$G = \frac{w_{totalUC}}{w_{BC} + w_{UC}} \tag{1}$$

In Equation 1, $w_{totalUC}$ describes the mean data rate that is required to serve all user requests individually by a single unicast network. The total necessary data rate of a hybrid network is symbolized by the sum of all broadcast channel capacities w_{BC} and of the remaining necessary unicast data rate w_{UC}.

The gain value increases if several users can be served by a single transmission via broadcast. Gain values greater than one bring a benefit for a hybrid network in the considered area in terms of saving data rate.

B. *Channel Popularity*

In the scenario an amount of TV-like channels is offered, denoted as C. They are provided by DVB-H if the number of requesting users is sufficient. These channels are called *broadcasted channels*, denoted as C_B. If the number of users requesting content of a channel is insufficient, this content is sent separately to each of these users by unicast.

A threshold of minimum listeners L_{min} is defined to decide on the type of transfer of content. As a simplification, a fixed threshold to switch content between the unicast and broadcast network was used. An optimized switching of content will be considered in the next steps of this research. In [9] an approach of optimized load balancing of content in a hybrid network can be found.

It is assumed that the utilization of channels is not equal for each offered channel. Thus, a Zipf popularity distribution (Equation 2) is used as described in [8].

$$P(i) = \frac{1}{\Omega i^{\alpha}} \text{ and } \Omega = \sum_{j=1}^{C} \frac{1}{j^{\alpha}} \text{ ; } 1 \leq i \leq C; \;\; i, C \in \mathbb{N}; \;\; \alpha \geq 0 \tag{2}$$

The popularity function depends on the number of offered channels C and the shape parameter α. With an increasing α the popularity decreases faster over the channels. $P(i)$ gives the probability of the usage of channel i. Using L_{min} the number of broadcasted channels C_B will be calculated (3.

In a DVB-H cell a mean number of potential users, denoted as N_{BC}, is demanding DVB-H services. The mean number of users of channel i results from multiplying $P(i)$ by N_{BC}. Channel i is broadcasted if the mean number of users demand that channel ($P(i) \cdot N_{BC}$) is greater than or equal to L_{min}. All broadcast users who are not served by broadcast channels are accumulated to $N_{BCviaUC}$ (4). Accordingly, $N_{BCviaUC}$ is the number of potential DVB-H users who are served by unicast.

$$\begin{aligned} C_B &= \sum_{i \in \{i | P(i) \cdot N_{BC} \geq L_{min}, 1 \leq i \leq C\}} 1 \\ &= min\left(C, \left(\left\lfloor \frac{N_{BC}}{L_{min} \cdot \Omega} \right\rfloor\right)^{\frac{1}{\alpha}}\right) \end{aligned} \tag{3}$$

$$\begin{aligned} N_{BCviaUC} &= N_{BC} \cdot \sum_{i \in \{i | P(i) \cdot N_{BC} < L_{min}, 1 \leq i \leq C\}} P(i) \\ &= N_{BC} \cdot \sum_{i=C_B+1}^{C} P(i) \end{aligned} \tag{4}$$

C. Gain Maps for Varying Radius

In order to find the optimal position and size of DVB-H cells, the gain value defined in (1) is used to build a gain map. A gain map is defined as a map of gain values for a fixed cell radius, at the same resolution and size as the scenario map. Each point of a gain map specifies the achieved gain if a DVB-H cell of the appropriate radius is placed at that position. Therefore, a gain value has to be calculated for each point of the scenario area. This process has to be repeated for each selected radius of DVB-H cells.

For the selected Nightscene scenario, 16 gain maps using radii from 250 m up to 4 km in steps of 250 m have been calculated. The lower limit of radius could be interpreted as a cell covering very small areas. Due to the limitation of area dimension (7.5 km) the upper limit was set to 4 km.

As an assumption, the number of channels was set to $C = 5$ and the popularity shape parameter was set to $\alpha = 2$. A shape value of two indicates a very dominating channel of about 68.3 % usage proportion. The remaining channels have a popularity of about 17.1 %, 7.6 %, 4.3 % and 2.7 %, respectively. Some of the less popular channels could offer general content such as news, whereas the more popular channels would provide Nightscene content. The threshold of minimum listeners was set to $L_{min} = 1$.

D. Placing of DVB-H Cells

In order to build a DVB-H network, position and size of cells have to be selected to maximize the benefit of a hybrid network. The gain maps defined in Section III-C will be used for placing DVB-H cells to achieve a maximum gain for a hybrid network.

It is assumed that a DVB-H network will be designed as an SFN (Single Frequency Network) using OFDM (Orthogonal Frequency Division Multiplexing) technique with 2K, 4K or 8K mode [10]. Due to the fact that cells can overlap, a parameter $O \in [0, 1]$ is defined. This parameter describes the maximum allowed overlap from one cell to another given as percentage of its radius. Furthermore, a minimum gain $G_{min} \in (1, G_{max}]$ (where G_{max} denotes the overall maximum gain) is selected to specify a lower limit of gain values. This parameter is expected to be greater than 1, otherwise a DVB-H cell at the appropriate position would not achieve a benefit for the hybrid network in terms of data rate.

In order to estimate the optimal position of DVB-H cells, all gain maps of a scenario are combined to a layered structure. Each layer then describes one gain map for a specific radius. The gain values for all radii at the same point of the map are sorted. Thus, for each point of the area a vector of sorted gain values and their associated radii is received. The top layer now contains the maximum gain map, where each point specifies the maximum achievable gain at the corresponding position of the area. The bottom layer holds the minimum gain values of each point.

Beginning at the top layer (maximum gain map), the first cell will be placed at the position of the overall maximum gain G_{max}. The next choice of position will be the biggest gain that satisfies the restrictions of overlap parameter O and minimum gain parameter G_{min}. If no more positions can be selected on the current map, the subjacent layer will be used further to place DVB-H cells according to the restrictions of O and G_{min}.

Figure 3 shows the DVB-H network consisting of five cells which was determined using the above-mentioned method. The minimum gain threshold was set to $G_{min} = 1.3$ including a margin for system costs, which will be analyzed in the next steps of this research. An overlap parameter of $O = 0.2$ was assumed. The reached gain values for each cell can be found in Table I.

It can be seen that DVB-H cells are placed in areas where potential users of such video content are located. Some of the specified Nightscene locations are not covered because the gain value is too small. In these areas, typical DVB-H content requested by the users will be transmitted by the unicast network.

IV. POWER ESTIMATION OF DVB-H TRANSMITTERS

Once the position and size of DVB-H cells have been determined, antenna height and transmitting power have to be estimated.

An algorithm described in Section IV-C was implemented to estimate the necessary transmitting power, EIRP (Effective Isotropic Radiated Power), of each DVB-H transmitter. This

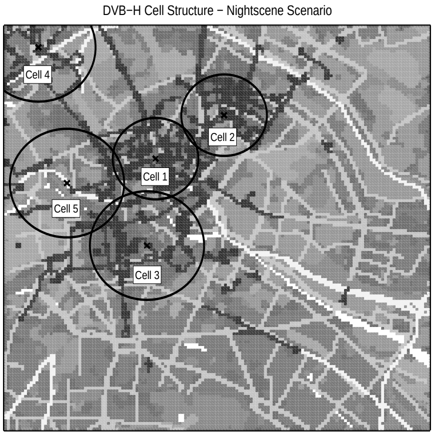

Fig. 3: *Placed DVB-H Cells for the Nightscene Scenario*

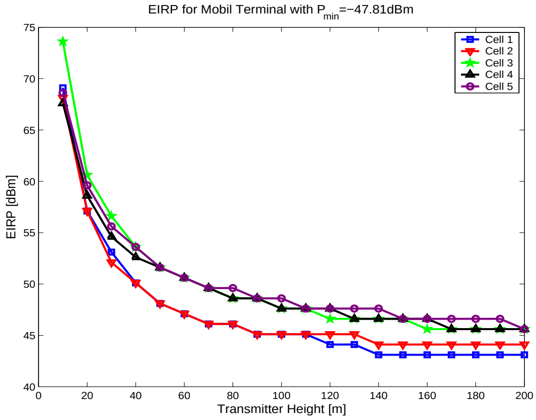

Fig. 4: *Estimated Transmission Power Depending on Transmitter Height*

algorithm is based on a propagation model which estimates the path loss to achieve a realistic coverage. For each DVB-H cell power estimation for different antenna heights (10 m-200 m in 10 m steps) was made.

A. DVB-H Parameters

A configuration of the DVB-H system and of a mobile terminal for DVB-H reception has to be assumed to determine the coverage area. According to [11] the following setting was used. An 8 MHz channel at a carrier frequency of 500 MHz was selected. The DVB-H reference receiver model with a 16-QAM modulation with code rate 2/3 was used.

A noise floor power level at the 8 MHz channel of $P_n = -100.2$ dBm is assumed. In [11] a minimum carrier-to-noise ratio of $C/N_{min} = 18.1$ dB and a 3 dB noise margin (N) are specified for the selected modulation type. An antenna gain for the mobile device of $G_a = -9.65$ dBi at 500 MHz is interpolated from given values. The antenna gain includes body loss and frequency deviation. In order to achieve a 99 % reliability, a fading margin of $F = 20.64$ dB was included, assuming a standard deviation for fading losses of 8 dB. A GSM reject filter is assumed which yields to an additional attenuation of $L_{GSM} = 1$ dB.

Using Equation 5, these values lead to a minimum receiving power level of $P_{min} = -47.81$ dBm. This value will be used to determine the coverage area and EIRP for each transmitter of the DVB-H network.

$$P_{min} = P_n + C/N_{min} + N - G_a + F + L_{GSM} \qquad (5)$$

It is to remark that all DVB-H specific values taken from [11] should be considered as preliminary and may change during the specification process.

B. Propagation Model

The COST 231 Walfisch-Ikegami propagation model [12] was selected to estimate the coverage area. It is verified for 800 to 2000 MHz and cell radii up to 5 km. It is assumed that this model is also valid for 500 MHz. In [13] it is shown that according to this model measurements and predictions fit best for antenna heights above 100 m. For a more realistic prediction in urban areas building data should have to be included. However, currently no building data are available at the public reference scenario of Berlin. Therefore, the prediction is based on land use classes defining different parameters for the propagation model. An omni-directional broadcast antenna type was selected. For each DVB-H transmitter several path loss predictions were made according to the selected antenna heights.

C. Adapting Transmitting Power

In order to estimate the necessary transmitting power for a selected DVB-H cell with the appropriate radius an algorithm was implemented which minimizes the difference between the predicted coverage and the assumed ideal circular cell. This method starts with a minimum power and calculates the coverage area for mobile reception specified in Section IV-A. Two error values are defined which describe the oversize outside and the not covered part inside the circular cell. The transmitting power will be increased in 1 dB steps until full coverage for the circle is reached. Afterwards, that power level will be selected which minimizes both deviances. The inside deviance is weighted stronger in order to reach an almost full coverage of the circular areas.

Figure 4 shows the estimated power for each of the five DVB-H transmitters of the Nightscene scenario depending on the transmitter height.

D. DVB-H Network Configuration

The necessary transmitting power for each DVB-H cell was determined for several antenna heights in the range of 10 m to 200 m. Due to the above mentioned lack of building data, accurate height information for roof-top antenna installations was not available. Instead, equal transmitter heights of 30 m for all DVB-H cells were used.

Table I shows a summary of significant parameters for all DVB-H cells of the achieved DVB-H network. Figure 5 shows the coverage area including the SFN gain of the DVB-H network configuration specified in Table I.

The OFDM mode should be selected according to the desired cell sizes and the maximum allowed speed of mobile users. The 2K mode is suitable for small cells (up to 17 km using a guard interval of 1/4) and allows extremely high speed reception, whereas 8K mode allows larger cell sizes (up to 67 km) with considerably less maximum speed. Due to small DVB-H cells selected for the Nightscene scenario, the 2K mode should be preferred allowing high speed mobile reception.

TABLE I: *DVB-H Cell Parameters of the Nightscene Scenario*

Cell ID	Radius [m]	Hybrid Gain	EIRP [dBm]	Antenna Height [m]
1	750	2.1427	53.11	30
2	750	1.8162	52.11	30
3	1000	1.6470	56.61	30
4	1000	1.3934	54.61	30
5	1000	1.3443	55.61	30

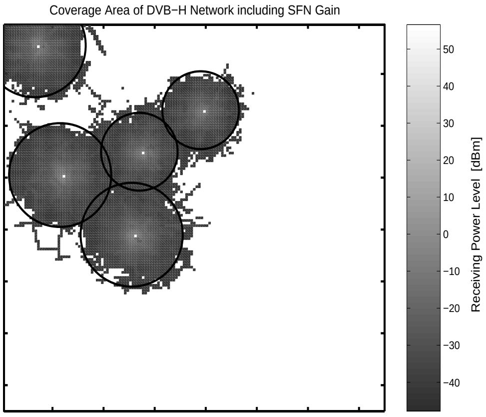

Fig. 5: *DVB-H Coverage Area for the Nightscene Scenario*

V. UNLOADING OF UTMS CELLS

In terms of hybrid networks, the installation of a broadcast network brings a benefit if UMTS cells are unloaded to achieve better QoS for UMTS users. The given UMTS network of Figure 1 was used to estimate the necessary data rates for the unicast network. The unloading of a UMTS cell is described by the ratio of data rates for a single unicast network to the unicast part of a hybrid network (Equation 6).

$$R = \frac{w_{totalUC}}{w_{UC}} \tag{6}$$

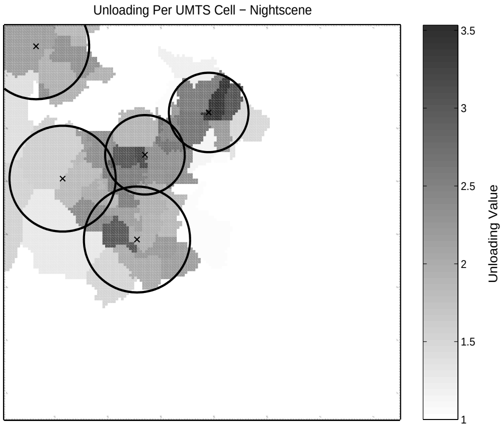

Fig. 6: *Unloading of UMTS Cells for the Nightscene Scenario*

Figure 6 shows the unloading for each UMTS cell and the estimated ideal DVB-H cell structure. It is obvious that UMTS cells are unloaded which are covered by DVB-H cells and if DVB-H channels are broadcasted to serve users. High unloading values are achieved at cells with high broadcast traffic and large number of users which are served by broadcast.

VI. CONCLUSION

A first approach for an automatic network planning method of hybrid mobile communication networks combining a unicast (UMTS) and a broadcast (DVB-H) network was shown. An example scenario which is based on the public reference scenario of Berlin from the IST-MOMENTUM project was used to prove the applicability of this method to estimate position, size and transmitting power of each cell of the DVB-H network. The results show that a hybrid network brings benefit to unload the unicast network by providing identical content to many users at the same time instead of separate transmissions.

The next steps of this research will contain the definition of a more realistic gain value including system costs of a hybrid network. A scenario including building data for a more realistic coverage and power estimation will be developed. Furthermore, the results of [9] will be used to include optimized load balancing for hybrid networks.

ACKNOWLEDGMENT

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