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Hot Spot Wireless LANs to Enhance the Throughput of "3G and Beyond" Networks

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ABSTRACT

At present, Wireless Local Area Networks (WLANs) supporting broadband multimedia communication are being deployed around the world. Standards include HIPERLAN/2, and IEEE 802.11a /802.11g. These systems provide channel adaptive data rates up to 54 Mbps over short ranges. It is likely that WLANs will become an important complementary technology to 3G cellular systems and typically used to provide 'hot-spot' coverage. In this paper, work performed under the framework of the IST ROMANTIK project for the use of WLANs in conjunction with UMTS is presented. In order to quantify the throughput enhancement benefits offered to a cellular network by wireless LAN technology, novel ray-tracing, software-simulated physical layer performance results and optimal base-station deployment analysis have been applied to inter-networking.

I. INTRODUCTION

WLANs provide high-speed wireless connectivity between PCs, laptops, and other equipment in corporate, public and home environments. HIPERLAN/2 [1-4], and IEEE 802.11a [5] are WLAN standards that will support multiple transmission 'modes', providing data rates up to 54 Mbps where channel conditions permit. An important application of WLANs is as a high-speed extension to cellular radio access networks. In particular, HIPERLAN/2 offers different convergence layers facilitating access to various core networks, such as Ethernet, IP and UMTS [4]. This interworking structure will enable the interaction of HIPERLAN/2 with evolving 3G mobile networks to be defined in a flexible and future-proof manner [6].

Within the context of 3G cellular systems, WLANs are a complementary technology that can be used to provide users with high data-rate services in localised areas. Handovers will be possible between 3G cellular access networks and WLAN access points. Although limited to small environments and pedestrian speeds, the increased capacity that is offered by WLANs is substantial. Note that HIPERLAN/2 operates as a connection-oriented wireless link. As such, it supports the differentiated Quality of Service levels required for transmission of the various media. Relative to cellular modems, WLANs achieve far higher bit rates although they are restricted to short range use. Hence, a user with a dual mode terminal will be able to take advantage of the higher data rates offered by the WLAN and the full range coverage of 3G cellular networks. In this paper, a propagation modelling tool, together with a physical layer simulation tool are used to determine the extra throughput offered by hot spot WLANs to an integrated 3G/WLAN system in an example area of central Bristol.

II. THE SIMULATION SET-UP

To study the use of hot spot WLANs to enhance the performance of 3G cellular networks, this paper focuses on a dense urban environment where capacity requirements are at their highest. To quantify the problem, the simulated deployment of a high capacity 3G network has been performed together with a WLAN hot spot overlay. This paper assumes the use of UMTS at 2 GHz and HIPERLAN/2 at 5GHz. However, due to physical layers similarities [2], our analysis with small modifications applies also for an 802.11a network. Hence, some results for 802.11a are also presented. A number of simulation tools developed by the authors [2,3,7-9] were combined in order to evaluate the performance enhancement that results when hot spot WLANs are deployed. These are: a) a propagation modelling tool, b) a basesite optimisation tool, c) a frequency allocation algorithm, and d) a WLAN physical layer simulator. These algorithms are described in the following subsections. Note that although the ROMANTIK project considers the use of WLANs in conjunction with UMTS in this paper only the throughput enhancements offered by the WLANs are presented.

A. The Propagation Model

A state of the art propagation model has been used to provide channel data for evaluating both the 5GHz HIPERLAN/2 and 2GHz cellular outdoor networks. The deterministic model uses geographic data to predict power as well as time, frequency and spatial dispersion in the radio channel [9]. It is optimised for intracellular coverage as well as inter-cellular predictions (interference) between different cells in a mixed-cell network. Propagation data is supplied for each base site in a list of potential base site locations. This data is then passed on to the optimisation module (see next section) and is used to optimise the number and locations of cellular and WLAN base stations. Complex channel impulse response data from the propagation model at the optimised wireless LAN access points is additionally provided and used in the physical layer simulations described in section III.

B. Basesite Optimisation Module

A novel optimisation algorithm that allows the optimum positioning of cellular and WLAN sites has been implemented. This algorithm is based on a combinatorial approach previously developed for cellular planning [7]. The new optimisation method has been re-designed to solve the problem of optimising cellular and/or WLAN site locations and density for different configurations and environments. To solve the optimisation/placement problem, the algorithm uses an over specified user defined group of possible sites. A complex analysis, based on combinatorial theory, is then performed before the final set of basesites is chosen. To carry out this analysis, the algorithm interacts with the propagation model, (described in the previous section) which supplies the necessary information to allow the selection of an optimal set of basesites [8].

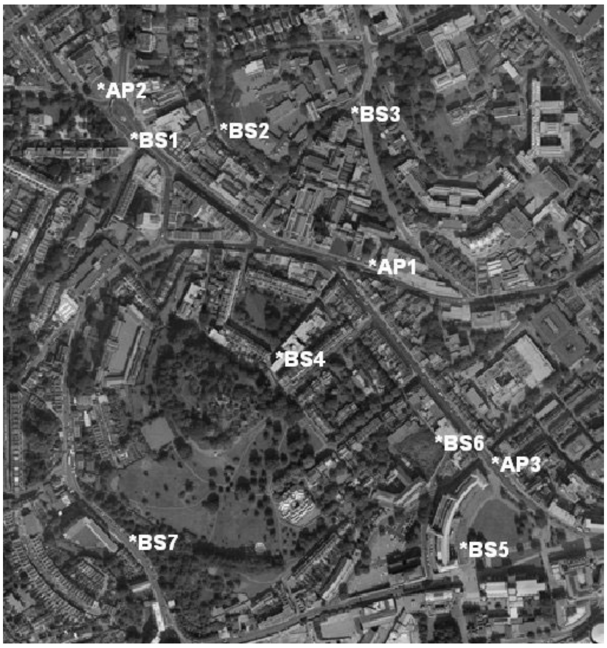

Figure 1: Locations of 7 BSs and 3APs

For the deployment of WLAN sites, the potential positions have been selected among street lamppost locations, while conventional locations have been used for the deployment of 3G (TDD UMTS) type base stations. The WLAN study has been performed at 5GHz; with omni-directional antennas at a height of 5m and AP transmit powers of 23dBm and 30dBm.

The optimisation process was performed over a one square kilometre area of central Bristol. 7 BSs and 3 WLAN sites were chosen to fulfil the coverage and capacity requirements. Figure 1 shows the locations of the chosen 3G base stations (denoted 'BS*') and WLAN access points (denoted 'AP*') on an aerial photograph of Bristol. Given the commercial/business character of this zone potentially requiring high data rate coverage, a second optimisation process was performed using 15 APs to cover 90% of the same area. The combined coverage of all the APs is shown in Figure 2.

C. Frequency Allocation Algorithm

The HIPERLAN/2 standard supports the use of Dynamic Frequency Selection (DFS) in order to minimise interference when multiple APs are employed in the network. Currently, 11 channels are available for use in the licence exempt band between 5.470-5.725 GHz with power limit EIRP of 30dBm for outdoor use. However, it is not known if all of them will be available for a single operator to use. Hence, in our paper, due to the limited number of frequencies available, frequency allocation was employed to minimise interference and to ensure that the proposed system will work when DFS is employed. The frequency allocation method makes use of combinatorial theory as well as the greedy algorithm [7]. The algorithms determine the number of frequencies that can be allocated to a specific number of APs to achieve a C/I threshold in the specified area. It has been assumed that the 3 APs in the first scenario operate at different frequencies so there is no interference between the WLANs. However the frequency planning algorithm was used for the case with 15 APs and the results showed that a minimum of 4 frequencies are required. Figure 2 shows a sample allocation of the four frequencies to the 15 APs.

Figure 2: Locations and frequencies of 15 APs

D. Physical Layer Simulator for WLANs

In order to evaluate the performance of WLANs for an outdoor environment, link level simulations have been performed utilising the channel information provided by the propagation model. A detailed PHY layer software simulation of HIPERLAN/2 and 802.11a has been developed previously by the authors [2]. For the purposes of this paper, the software simulation has been employed to evaluate performance in terms of PER and throughput versus SNR for the radio channels indicated by the propagation tool described in subsection (a). Additionally, the performance improvement in throughput and coverage is demonstrated. The propagation modelling tool was employed to provide path loss (or received signal strength) and channel data for the outdoor environment. Coverage maps were then generated for each AP. Subsequently, the throughput results are used to translate the received signal power into achievable data rate for the WLANs.

III. PHYSICAL LAYER PERFORMANCE RESULTS

The physical layer of HIPERLAN/2 and IEEE 802.11a/g are based on the use of OFDM. OFDM is used to combat frequency selective fading and to randomize the burst errors caused by a wideband-fading channel. OFDM modulation is implemented by means of an inverse FFT. 48 data symbols and 4 pilots are transmitted in parallel in the form of one OFDM symbol. In order to prevent ISI, a guard interval is implemented by means of a cyclic extension. When the guard interval is longer than the excess delay of the radio channel, ISI is eliminated.

Table 1: Mode dependent parameters

Mode	Modulation	Coding rate	Bit Rate [Mbit/s]
1	BPSK	1/2	6
2	BPSK	3/4	9
3	QPSK	1/2	12
4	QPSK	3/4	18
5	16QAM	9/16	27
6	16QAM	3/4	36
7	64QAM	3/4	54

Importantly, the physical layer provides several modes (Table 1) each with a different coding and modulation configuration [2]. These are selected by a *link adaptation* scheme. A simple approximation of the link throughput when retransmission is employed is given by: *Throughput = R (1-PER)*, where *R* and *PER* are the bit rate and packet error rate for a specific mode respectively. In this paper, a simple link adaptation scheme has been employed, in which the mode with the highest throughput is chosen for each instantaneous SNR value.

After processing the channels that were obtained from the propagation modelling tool for the WLAN sites specified, link level simulations were performed. For each WLAN site, ~2000 complex impulse responses (CIRs) corresponding to a mixture of line of sight and non line of sight points were obtained in a specified area. These channel realisations were used to obtain an average PER performance for the specified area. The average rms delay spread for the area around AP1 (shown in Figure 1) was τ_{rms}=55ns. Figures 3 and 4, show performance results for AP1, in terms of PER and throughput respectively. Note that Medium Access Control (MAC) overheads for HIPERLAN/2 have also been taken into account when calculating the throughput [2, 3]. The maximum throughput after MAC overheads is 42Mbps for HIPERLAN/2. The maximum throughput after the MAC overheads for IEEE 802.11a depends on the packet size since variable packet sizes can be used [2]. When a packet size of 1500 bytes is used the maximum throughput is 31Mbps [2]. The same procedure was repeated for the other APs and similar results were obtained. To translate the SNR values to received power, equation (1) was used where *NF* is the noise figure (8dB), *K* is Boltzmman's constant, *T* is temperature (290K) and *B* is the bandwidth:

$$Rx\ Power\ (dBm) = SNR\ (dB) + KTB\ (dBm) + NF\ (dB) \quad (1)$$

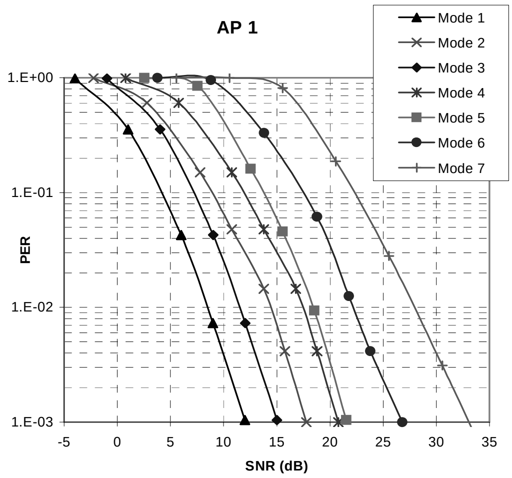

Figure 3: PER performance for AP1 for HIPERLAN/2

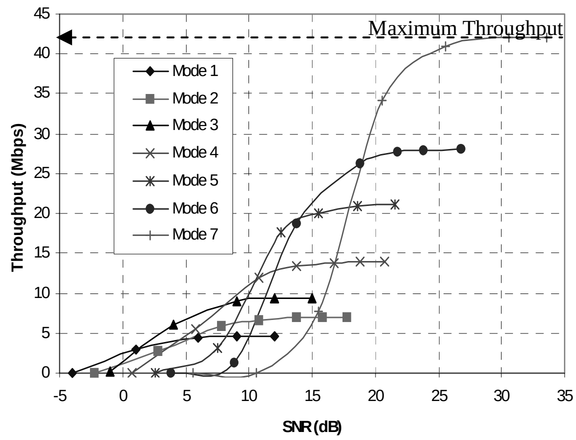

Figure 4: Throughput versus SNR for HIPERLAN/2

IV. COVERAGE AND THROUGHPUT ANALYSIS

For the purposes of this paper, the propagation modelling tool has also been employed to provide a point-to-multipoint analysis of the received signal level at 5.2GHz, in the outdoor WLAN environment for AP locations as illustrated in Figures 1 and 2. Based on the predicted coverage and the throughput performance of HIPERLAN/2 and IEEE 802.11a, it is possible to evaluate the maximum achievable data rates throughout the coverage area for each location.

Considering the first case (3 APs), Figures 5 and 6 show the coverage achieved for predefined areas around the APs for transmit powers of 30dBm and 23dBm. Figures 7, 8 and 9 compare the corresponding throughput achieved for HIPERLAN/2 with transmit powers of 30dBm and 23dBm and for IEEE 802.11a with transmit power of 30dBm (packet size of 1500 bytes). It can be seen that the use of the maximum 30dBm transmit power results in almost continuous or overlapping coverage over the defined areas. On the other hand, the reduced transmit power of 23dBm leads to a lower proportion of the defined areas receiving significant energy. The reduced throughput of 802.11a is due to the higher overhead of the standard as described in the previous section. It can be seen that higher modes corresponding to high data rates are used for a high proportion of the area and then the modes degrade rapidly. This is due to the propagation characteristics at 5GHz in a high building density outdoor environment where the signal attenuation with distance is very high.

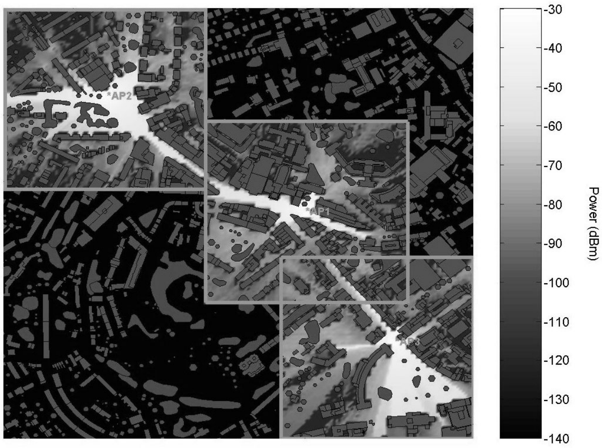

Figure 5: Coverage map for 3 APs, 30dBm transmit power

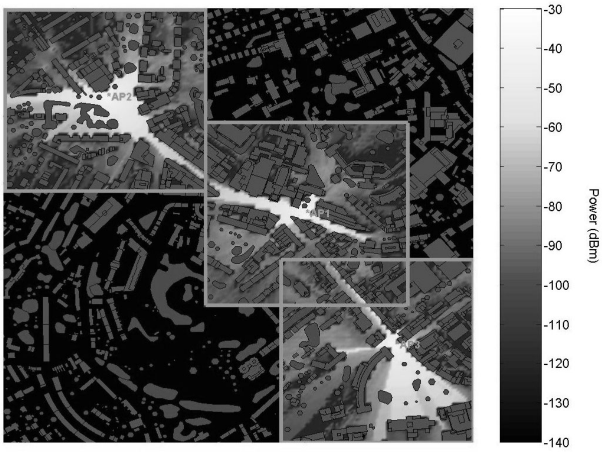

Figure 6: Coverage map for 3 APs, 23 dBm transmit power

Figures 10 and 11, show the corresponding coverage and throughput respectively for the case with 15 APs. These figures show that most of the 1km x 1km area is covered with the 15 APs (with 4 frequencies) and higher modes (throughput) are used in a higher proportion of the area. These results are further illustrated in Figure 12 which compares the area achieving a specific data rate for both 3 AP and 15 AP scenarios. The area achieving throughputs > 15Mbps for instance increases from 62000sq.m for the 3 APs HIPERLAN/2 case with 23dBm transmit power to 95000sq.m when the transmit power increases to 30dBm. For the same transmit power (30dBm), IEEE 802.11a covers only 74000sq.m. Additionally it can be seen that above 25Mbps, HIPERLAN/2 at 23dBm transmit power covers a larger area than IEEE 802.11a at 30dBm transmit power. As expected, the area covered with the 15 APs is considerably larger for all throughput levels. For example, it can be observed that the area achieving data rates in excess of 15Mbps for the 3 APs scenario now achieves a data rate in excess of 38Mbps for the same transmit power with 15 APs.

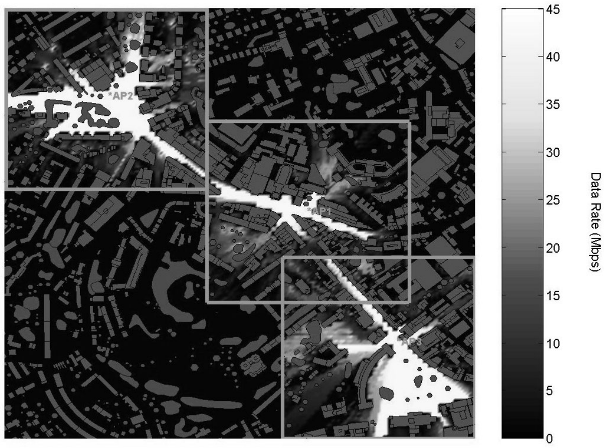

Figure 7: Throughput map for HIPERLAN/2, 30dBm transmit power.

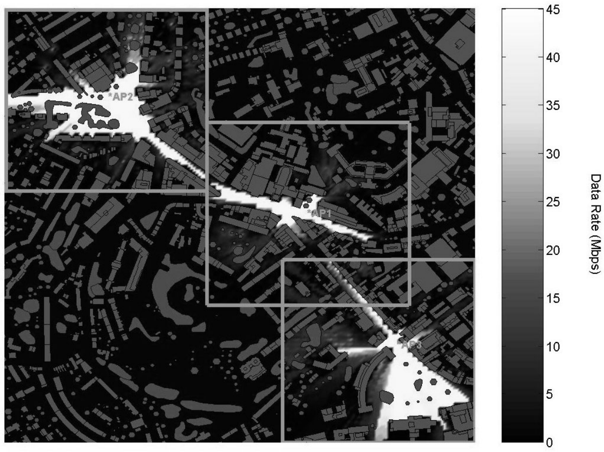

Figure 8: Throughput map for HIPERLAN/2, 23dBm transmit power.

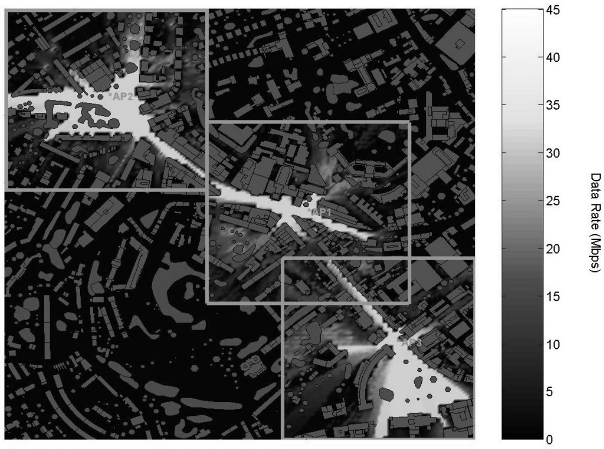

Figure 9: Throughput map for 802.11a, 30dBm transmit power (1500 bytes packet size)

V. CONCLUSIONS

In this paper channel data from a 3-D site-specific propagation model together with physical layer simulation tools have been used to simulate the coverage and throughput offered by WLANs to an integrated WLAN-3G system in a microcellular urban environment. Two cases have been examined for the WLANs: one case with 3APs and the other with 15 APs where a frequency allocation algorithm has been employed to assign 4 frequencies to the APs. Coverage and throughput maps have been produced for the different cases, including results for both HIPERLAN/2 and IEEE 802.11a and different AP transmit powers. A comparison of the area covered for the different scenarios and transmit powers has shown that for higher data rates, HIPERLAN/2 type WLANs cover a larger area compared to IEEE 802.11a WLANs. As expected, the 15 APs were shown to cover a large proportion of the network area and with high data rates well over the 2Mbps rate achievable by 3G systems. On going work, includes the translation of this extra throughput introduced by the WLANs to capacity enhancements of the 3G networks. Early studies look very promising, showing high increases of the system capacity (in terms of number of users) when WLAN-3G interworking is employed.

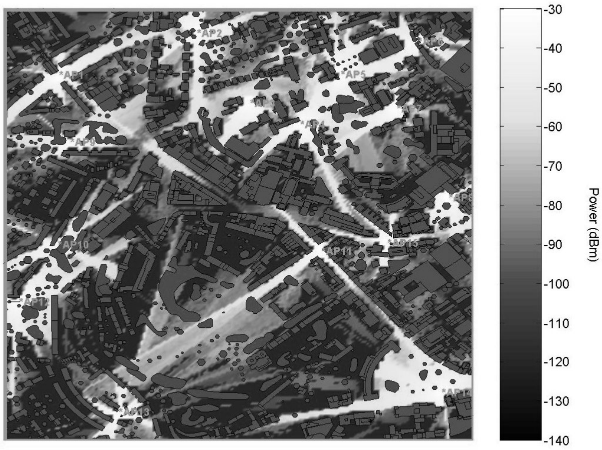

Figure 10: Coverage map for HIPERLAN/2 with 15AP, 30dBm transmit power

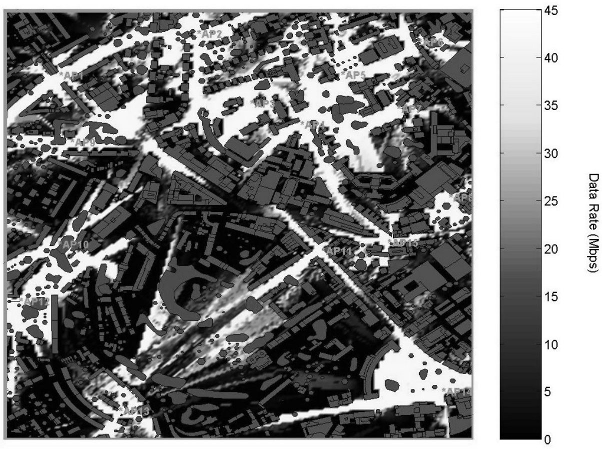

Figure 11: Throughput map for HIPERLAN/2 with 15AP, 30dBm transmit power

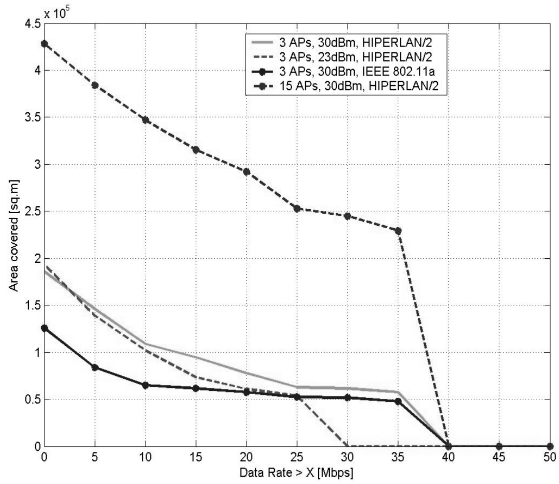

Figure 12: Throughput area distribution comparison

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REFERENCES

[1] ETSI, “Broadband Radio Access Networks (BRAN); HIPERLAN type 2 technical specification; Physical (PHY) layer,” August 1999. <DTS/BRAN-0023003> V0.k.

[2] A. Doufexi, S. Armour, P. Karlsson, M. Butler, A. Nix, D. Bull, J. McGeehan, “A Comparison of the HIPERLAN/2 and IEEE 802.11a Wireless LAN Standards,” IEEE Communications Magazine, May 2002, Vol. 40, No. 5.

[3] A.Doufexi, S.Armour, P.Karlsson, A.Nix, D.Bull, "Throughput Performance of WLANs Operating at 5GHz Based on Link Simulations with Real and Statistical Channels," IEEE VTC’01 Spring (Rhodes).

[4] J. Khun-Jush, G. Malmgren, P. Schramm, J. Torsner “Overview and Performance of the HIPERLAN/2 –A Standard for Broadband Wireless Communications,” IEEE VTC’00 Spring (Tokyo).

[5] IEEE Std 802.11a/D7.0-1999, Part11: Wireless LAN Medium Access Control and Physical Layer specifications: High Speed Physical Layer in the 5GHz Band.

[6] ETSI TR 101 957, "Broadband Radio Access Networks (BRAN); HIPERLAN Type 2; Requirements and Architectures for Interworking between HIPERLAN/2 and Third Generation Cellular systems", V1.1.1, August 2001.

[7] A. Molina, G.E. Athanasiadou, A. Nix, “Cellular Network Capacity Planing Using the Combination Algorithm for Total Optimisation”, IEEE Vehicular technology Conference, Vol.3, pp. 2512-2516, Tokyo, , May 2000.

[8] A.Molina, G.E. Athanasiadou, A. Nix, “The Automatic Location of Base-Stations for Optimised Cellular Coverage: A New Combinatorial Approach”, VTC 99, Houston.

[9] E. K. Tameh, A.R Nix, "A Mixed-Cell Propagation Model for Interference Prediction in a UMTS Network", VTC 2001 Spring, May 2001.

[10] ETSI, “UMTS UTRA (UE) TDD: Radio Transmission and Reception”, 3GPP TS 25.102 v4.3.