3.5 GHZ BROADBAND FIXED WIRELESS NETWORK DESIGN FOR RURAL DEPLOYMENT

Desmond M. Ryan, Stuart M. Allen, Stephen Hurley, Richard K. Taplin, and Nils K. Elnegaard

***Abstract*— This paper uses an automated cell planning tool to assess commercial aspects affecting the deployment of Broadband Fixed Wireless Access (BFWA) networks operating at 3.5 GHz in rural areas. ECHO [1, 2], the tool used, was developed in the IST project EMBRACE [3]. We design networks, at 0.512, 2 & 5 Mbit/s service bit-rates, where the mean user densities vary between 3 and 17 households (HH) per km^2, and we consider low (50-70%) and high (90%) coverage requirements. The optimisation is driven by the net present value (NPV) of the network calculated over an eight-year period. The results show that for the given service the cost to deploy the network per user flattens above 12 HH/ km^2. This result and the techniques used to derive it will assist in defining an effective subscription/tariff strategy. Also when the rural household density is 17 (or above) BFWA can compete with ADSL services in some countries. The network roll-out period, at 0.512 & 2 Mb/s service bit-rates, is investigated for the high coverage 17 HH/ km^2 rural scenario, and the optimum period is found to be 3 years for both service bit-rates.**

***Index Terms*—Broadband Fixed Wireless Access, Network design, Cell Planning, Network rollout**

I. INTRODUCTION

THE use of automated planning tools in designing wireless communications networks has become widespread [4-13], primarily in the area of mobile telephony. Although their main use has been in producing and configuring individual networks, they also have an important role to play in evaluating different economic and technical scenarios. Since they produce near optimal network designs in a fraction of the time of a manual planner, their repeated use allows an operator to accurately assess the effect of changing technologies, architectures, frequency bands, etc. in practical situations. In this paper, such a tool is used to assess the feasibility of deploying BFWA networks, operating at 3.5 GHz, in rural scenarios, and determine the parameters which may make these networks economically competitive with other broadband technologies.

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II. INTELLIGENT NETWORK DESIGN

The ECHO planning system [1,3] is an optimisation tool for planning cost effective BFWA networks. The tool is based on a financial model reflecting the cost and revenue of the network in question over suitable return periods. Adding infrastructure, such as base stations, antennae etc, incurs a financial cost, while supplying a service to customers provides revenue to the supplier. The network infrastructure is split into three elements: (i) base stations – where the associated costs cover installation and annual management to operate the site over the specified return period, (ii) sectors – where each sector consists of a single antenna, and (iii) users – each user represents a potential subscriber in the network area and is specified by their traffic requirements, predicted revenue over the return period, quality of service (availability), a list of possible reception points where an antenna could be placed, and the probability of subscription (with a value between 0 and 1). While it is possible to set all these parameters for each individual user, it is more usual to group the users into broad classes such as residential, small home office, and small/medium enterprise, with each class sharing the same parameter profile. Path loss data between the base stations and users is used in conjunction with the antennae configuration parameters (antenna type, power, radiation characteristics, tilt and azimuth to calculate network coverage. The design process configures each element of the network infrastructure to give near optimal performance. The main operation is the placement and configuration of sectors at base station sites in order to maximise coverage, minimise over capacity in cells, minimise interference and minimise infrastructure costs. All of these objectives serve to maximise the net present value (NPV) which is the summation of the discounted cash-flows over the time period in question [16]. In this study the NPV is calculated over an 8 year period. The planning tool also optimises the channel assignment from the available spectrum to mitigate interference. The design of the network has three phases: (i) initialisation, (ii) repair, and (iii) optimisation, and proceeds by making small changes to the network, such as adding a new sector, reconfiguring an existing sector, or changing the channel assignment. The initialisation phase generates a number of sectors based on the traffic demand in the network area. These sectors are randomly configured. The repair phase takes this network and repeatedly applies modifiers until the coverage constraint is satisfied. Finally, the optimisation phase improves the design of phase two using a selection of operations that target network deficiencies and optimises for NPV. The key to the success of the optimization phase is in the intelligent choice of design modifier, and in the meta-heuristic algorithm used to control the process. In this study the tabu search meta-heuristic [14] is applied in which a memory of past modifications is used to prevent cycling in local optima which are not globally optimal.

III. NETWORK SCENARIO

Randomised household and potential base site coordinates were generated in a 10 x 10 km square (100 km^2) at three different densities, namely 3, 12, & 17 HH/ km^2, which we will refer to as low, medium and high rural density respectively. These values correspond to the mean household densities of rural regions in Norway, France and Poland respectively [17]. The high density, 17 HH/ km^2, rural scenario is shown in Fig. 1.

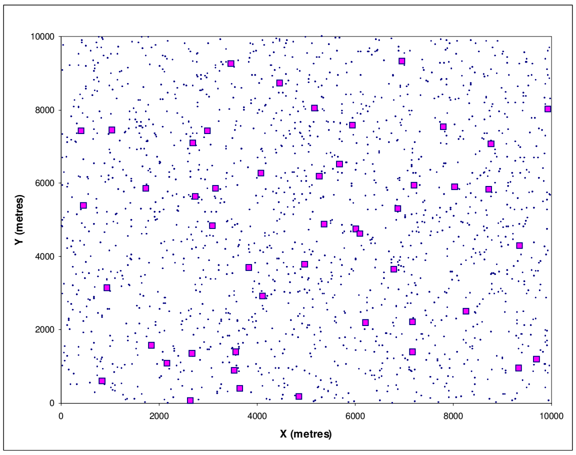

Fig. 1: The high density rural scenario. Each dot represents a household, whilst the solid squares represent potential base-sites (48 in total).

In this case study the topology is assumed to be flat, however this is not a requirement. More accurate representations of the household distribution and terrain can be used to consider more specific regions. The path loss between each potential base site and each household/user was calculated using the method described in IEEE802.16 [15]. It is assumed also that all base-site and sector equipment is deployed in year 1. The main assumptions used for the calculations in this case study are shown in Table 1.

In this work the product (market-share)x(take-rate) yields the probability that a household will subscribe to the service, and is different for each year.

Base Site Installation Cost	€30,000
Base Site Maintenance Cost (annual)	€200
Sector Antenna (15, 30, 45, 60 or 90 degrees) Cost	€3,000
HH Antenna Cost (low, medium, or high gain)	€750
HH Installation (external works for antenna mounting etc)	€200
One-off connection charge per HH	€50
Market Share	100%
Churn rate	5%
Return period	8 years
Take Rate for years 1->8	5, 13.8, 24.4, 33.5, 40, 44.2, 46.7, & 48.1%
Discount Rate	12%
Channel bit-rate	26.33 Mb/s
Maximum Channels per sector	12
Required availability	99.99%
Service bit-rates	0.512, 2 & 5 Mb/s

Table 1: Shows the main assumptions used for all network designs.

IV. RESULTS

The ECHO Planning system is used to design 3.5 GHz BFWA rural networks, at three household densities, so as to return an NPV value of zero, i.e. breakeven. For each of the household density scenarios, networks are designed for three service bit-rates, namely 0.512, 2 & 5 Mbit/s. Also, the effect of low coverage (~50-70%), and high coverage (~90%) networks on the NPV is examined. Fig. 2 shows the variation of break-even annual household subscription (the subscription which returns an NPV~0) versus service bit-rate at constant coverage for each of the three densities.

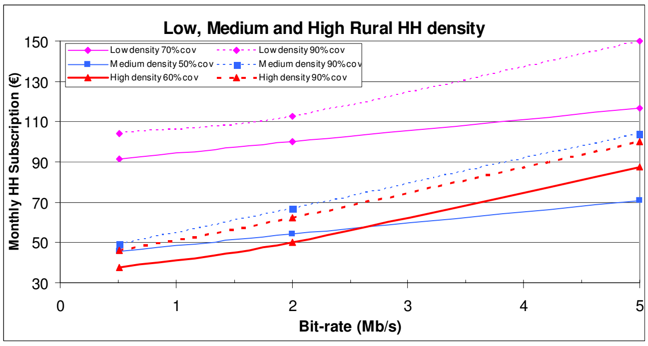

Fig. 2: Variation of break-even household subscription (per annum) versus service bit-rate (Mb/s) for networks deployed in low, medium and high density rural areas. The calculated NPV, in all cases, is approximately zero.

There are two constant coverage contours for each, one for low coverage (50-70%), and the other for high coverage (90%). Each discrete point also corresponds to a network with an NPV value close to zero. In general, household subscription increases linearly with increasing service bit-rate (at constant coverage), and household subscription increases with increasing coverage (at constant bit-rate) for each density respectively. As a comparison, the current ADSL monthly subscriptions, for a nominal 512 kbps ADSL service, in

Norway, France and Poland are approximately €42, €21 and €36 respectively [18]. Inspection of the figure, at a bit-rate of 512 kbps, shows that the break-even household subscription, on the low coverage curve (Fig. 2), for high density is similar to the current ADSL subscription level, which implies that the proposed 3.5 GHz network in rural Poland could compete directly with cable ADSL service providers in areas with high household densities. In general however, as break-even household subscriptions are higher than current ADSL subscriptions, grants or subsidisation by regional or national actors are required in order to produce viable rural networks. Fig. 3 shows the variation of discounted capital expenditure (summed over 8 years) divided by the number of subscribed households in year 8 versus service bit-rate.

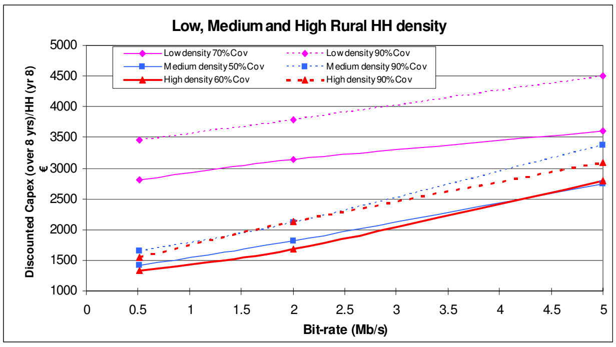

Fig. 3: Variation of [discounted capital expenditure (summed over 8 yrs)/No. of subscribed HHs in yr 8 versus service bit-rate (Mb/s) for networks deployed in low, medium and high density rural areas.

As expected, the metric increases with increased service bit-rate (at constant coverage), and also increases with increasing coverage (at constant bit-rate). In other words, the cost to the operator, to serve a rural household, increases with network coverage, and service bit-rate. What can be inferred from this graph is the magnitude of the discounted revenue (per HH), which must be generated in order to make a network profitable. Interestingly, the curves for medium and high densities are very similar, which implies that the discounted capital expenditure to serve a household is the same in both of these cases. The next figure provides us with a better understanding of this result. Fig. 4 shows the variation of discounted capital expenditure (summed over 8 years) divided by the number of subscribed households in year 8 versus rural network household density, at three service bit-rates. The coverage is about 90% in all cases. Fig. 4 tells us that it is more expensive to serve a household in a low-density area than it is in a high-density area, and that cost increases with increasing service bit-rate. However, more interestingly, the

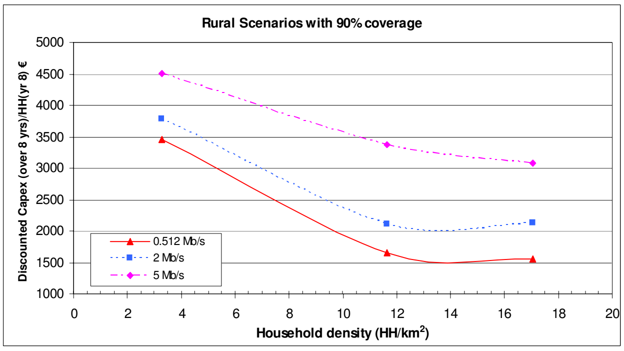

Fig. 4: Variation of [discounted capital expenditure (summed over 8 yrs)/No. of subscribed HH in year 8 versus Household density (HH/km^2) for 90% coverage rural networks.

discounted capital expenditure (CAPEX) saturates (or becomes nearly constant) above the household density of 12 HH/ km^2. This implies that, for rural wireless networks with a household density greater than 12 per km^2, the cost to serve a household is the same. This explains the similarity between the medium and high density results in Fig. 3, since both of these scenarios have a household density of ~12 HH/ km^2 or greater. This result could provide guidance in determining a comprehensive rural pricing strategy for broadband service provision to rural customers.

Additionally, for the high household density case the ECHO Planning system is used to examine the effects of network rollout on the NPV at two service bit-rates, namely 0.512 & 2 Mb/s. All the results presented thus far assumes the deployment of all base and sector equipment in year 1, whilst the user equipment is deployed when service is activated. We will refer to this type of deployment as a 1 year rollout. The rollout periods (to achieve ~90% coverage) examined are 2, 4 & 8 years. The calculated NPV for each of the rollouts is shown in Table 2.

Roll-out period	NPV (K€) at 0.512 Mb/s	NPV (K€) at 2 Mb/s
1	52	19
2	116	174
3	247	265
4	86	58

Table 2: Shows the effect of network rollout on the calculated NPV for network designs for the high density rural scenario at 0.512 & 2 Mb/s services. The target coverage for each rollout is 90%.

The results show that the optimum rollout period for the high density rural scenario (17 HH/km^2) is 3 years for both 0.512 Mb/s and 2 Mb/s networks.

V. SUMMARY

We design 3.5 GHz BFWA rural networks, at 0.512, 2 & 5 Mbit/s service bit-rates, and consider the low coverage (50-70%), and high coverage (90%) cases for three household densities. The optimisation metric (for ECHO) is net present value (NPV) and is calculated over an eight-year period. The results show that above 12 HH/ km^2 (for a given service) the cost to deploy the network per user saturates, and it is this result that may assist in defining a comprehensive subscription/tariff strategy. Also when the rural household density is 17 (or above) BFWA can compete with ADSL services in some countries. In addition, network rollout results show that the optimum rollout period for the high density rural scenario (17 HH/ km^2) is 3 years for both 0.512 Mb/s and 2 Mb/s networks. More accurate representations of the household distribution, terrain and path loss can be used to consider more specific regions, and techniques presented can be utilised to determine the appropriate user subscriptions level, and optimum network rollout.

ACKNOWLEDGEMENT

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REFERENCES

[1] S.M. Allen, K. H. Craig, S. Hurley, W. D. Miners, and R. K. Taplin. *A software tool for optimised millimetric radio access cell planning*. IST Mobile and Wireless Telecommunications Summit, Thessaloniki, Greece, 2002.

[2] M.D. Louta, P. P. Demestichas, E. D. Loutas, S. K. Kraounakis, M. E. Theologou, and M. E. Anagnostou. *Cost-efficient design of future broadband fixed wireless access systems*. Wireless Personal Communications, 27, pp. 57–87, 2003.

[3] R. K. Taplin, S. M. Allen, S. Cirstea, K. H. Craig, S. Hurley, W. D. Miners, J. Norbury, and M. Willis. *Cell planning optimisation tool*. Technical report, EMBRACE public deliverable D17, 2002.

[4] A. Molina, G.E. Athanasiadou, and A. R. Nix. *The automatic location of base-stations for optimised cellular coverage: A new combinatorial approach.* IEEE Vehicular Technology Conference 1999.

[5] H. D. Sherali, C. M. Pendyala, and T. S. Rappaport. *Optimal location of transmitters for micro-cellular radio communication system design*. IEEE Journal on Selected Areas in Communications, 14(4), pp. 662-673, 1996.

[6] G. L. Siqueira, E. A. Vasquez, R. A. Gomes, C. B. Sampaio, and M. A. Socorro. *Optimization of base-station antenna position based on propagation measurements on dense urban microcells*. IEEE Vehicular Technology Conference, 1997.

[7] K. Tutschuka, N. Gerlich, and P. Tran-Gia. *An integrated cellular network planning tool*. 47th IEEE Vehicular Technology Conference, pp. 765-769, 1997

[8] S. J. Fortune, D. M. Gay, B. W. Kernighan, O. Landron, R. A. Valenzuela, and M. H. Wright. *Wise design of indoor wireless systems*. IEEE Computat. Sci. Eng., 2(1), pp. 58-68, 1995.

[9] P. Calegarie, F. Guidec, P. Kuonen, B. Chamaret, S. Udeba, S. Josselin, and D. Wagner. *Radio network planning with combinatorial algorithms*. ACTS Mobile Commun., pp. 707-713, 1996.

[10] T. Fruhwirth, J. Molwitz, and P. Bisset. *Planning cordless business communication systems*. IEEEExpert Mag., pp. 662-673, 1996

[11] T. Lissajoux, V. Hilaire, A. Koukam, and A. Caminada. *Genetic algorithms as prototyping tools for multi-agent systems: An application to the antenna setting problem*. Lecture notes in Computer Science, 1997, 1437, pp. 17-28

[12] L. Ibbetson and L. Lopes. *An automatic base site placement algorithm*. IEEE Vehicular Technology Conf., 1997

[13] P. Reininger and A. Caminada. Model for GSM radio network optimization. 2nd ACM Intl Conf. Discrete Algorithms and Methods for Mobility. Dallas, TX, 1998

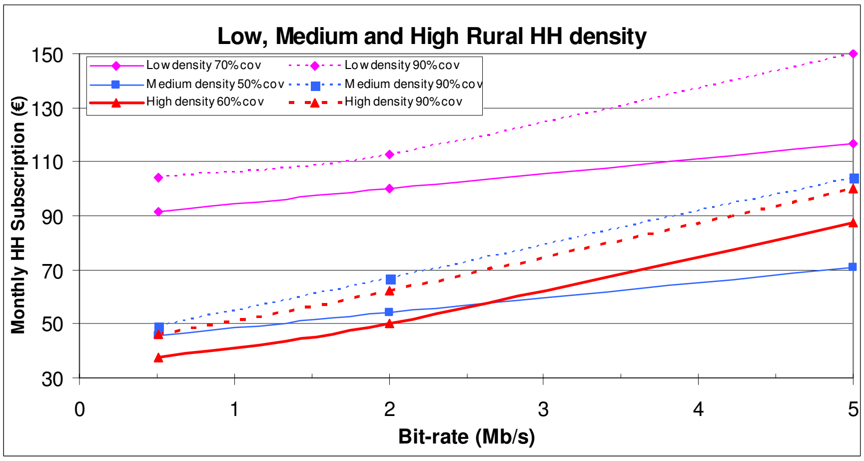
[14] C. R. Reeves, *Modern heuristic techniques for combinatorial problems*. McGraw-Hill, 1995

[15] *IEEE802.16a-2003 Part 16, pp. 281-283, 2003*

[16] J. C. Hull, *The evaluation of risk in business investment*, Pergamon Press (Oxford, UK), 1980

[17] G. Bichot, I. Tardy, J. R. Norbury, P. Hirtzlin, L. E. Bråten, J. Lopez, M. Menozzi, M. Coraggi, G. Auger, S. Nagar, I. Frigyes, G. F. Vezzani, M. Schmidt, O. Grøndalen, M. Goldhammer, S. Paillard, Achieving broadband delivery in rural area, EU FP6 Broadwan project Deliverable D9, 2004.

[18] R. Montagne and N. K. Elnegaard, *Broadband access roadmap based on market assessment and technical-economic analysis*, EU FP6 Broadwan project Deliverable D15, 2004



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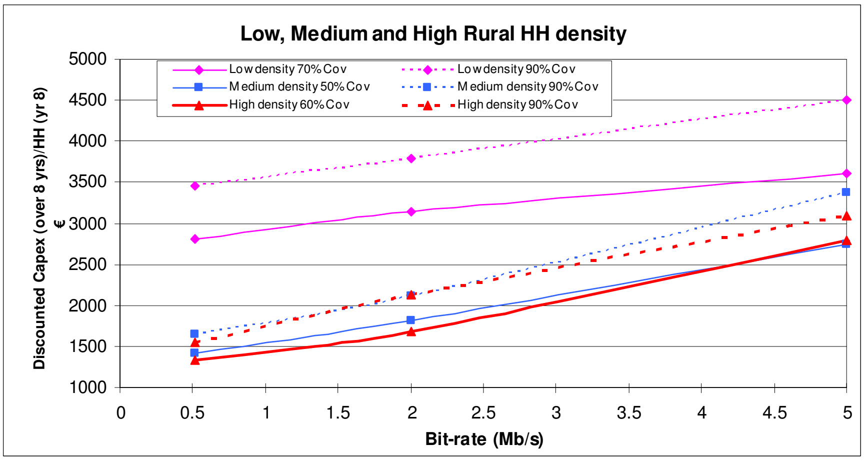

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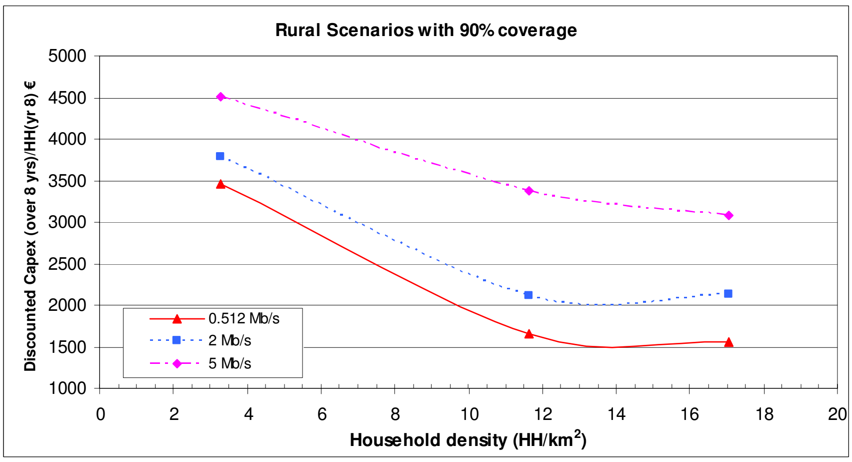

Fig. 4: Variation of [discounted capital expenditure (summed over 8 yrs)/No. of subscribed HH in year 8 versus Household density (HH/km^2) for 90% coverage rural networks