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Techno-economic Case for a Remote WiMAX Cell

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Introduction

Problem of providing reliable and economically sustainable modern digital telecommunications services in remote rural areas is not new, and using Fixed Wireless Access (FWA) systems had been previously suggested as being one of the most appropriate solutions to resolving this problem [1].

After certain decline, the revival of FWA technology had been recently promised by the development of OFDM-based technologies, with IEEE 802.16 [2], also known as WiMAX. OFDM technology provides a more robust communication over radio channel thus allowing reaching User Terminals (UT) at larger distance and at disadvantaged positions such as those without direct Line-of-Sight (LOS) to a Base Station (BS).

The viability of WiMAX deployment was addressed by several authors, but mostly limited to economics of larger networks [3] or those deployed in densely populated clusters [4]. Still, an example of country like Lithuania poses a question whether systems such as WiMAX could be also viable in scarcely populated rural areas, where they could be deployed either as part of coverage by nation-wide networks or as independent community-driven singular cells.

It is therefore a purpose of this paper to discuss some elements of estimating technical and economical feasibility of building singular WiMAX coverage spots in remote sparsely populated rural areas, using 3.5 GHz band.

Describing the task

This paper will consider technical and economic viability of deploying a stand-alone WiMAX cell (or cluster of sectored cells) in a scarcely populated rural area. While the voice telephony application is likely to remain an important part of telecommunications service offering, we consider that the main driving factor for deploying systems such as WiMAX would be requirement for high/higher bitrate data services. This scenario would be typical for many small towns and villages in provincial areas of our country where DSL coverage is still patchy, although incumbent PSTN operator makes significant efforts to reach rural areas with DSL [5].

To study the feasibility of deploying a WiMAX cell in remote areas, this paper considers the technical aspects of sufficient capacity as well as range, and concludes with reviewing the economic business case.

Capacity considerations

For the purpose of traffic estimation we base our considerations only on the necessity of providing a certain data bitrate channel, assuming that an eventual voice communication channel could be reliably carried within the same bitstream.

It should be possible to obtain the maximum number of UTs that may be supported by capacity of a single BS transceiver, by using following expression:

$$N_{UT} = \frac{A_{BS} \cdot k_{os}}{A_{sub}}, \quad (1)$$

where A_{BS} – the maximum capacity supported by BS, k_{os} – an over-subscription factor and A_{sub} – a subscription capacity of a single UT, in this case considered constant for simplicity purposes.

Looking at (1) one may notice that all of the factors may be influenced by operator, such that A_{BS} will depend on the equipment configuration and the choice of modulation, k_{os} may be set depending on the type of expected usage and the desired availability objectives, and A_{sub} will be naturally predetermined by the subscriptions offered to the users.

A typical WiMAX setup could envisage the following configuration of the above parameters:

- A_{BS} = 75 Mb/s,
- k_{os} = 4,
- A_{sub} = 2 Mb/s,

whereas (1) would return the maximum number of supported UTs of N_{UT}=150 per sector/channel.

This would be clearly a sufficient ceiling for typical rural deployment, however, the problem is that the bandwidth supported by a BS will actually depend on the communications range, i.e. maintaining the reliable high bitrate link to a remote subscriber will require using lower modulation state and higher power, thus cannibalising the total bandwidth and power resources of a BS [6]. We shall return to considering this phenomenon after introducing the issue of coverage range prediction via propagation modelling in next section.

Propagation modelling issues

A good analysis of suitable options for modelling of coverage of FWA systems was given in [7], where it was shown that for FWA systems above 2 GHz one reasonable option would be to use a well known Free Space Loss (FSL) model:

$$L_{FSL} = 32.45 + 20\log(f) + 20\log(r) \text{ [dB]}, \qquad (2)$$

here expressed for f – operating frequency in MHz, and r – link distance, km.

Using FSL requires an assumption of (nearly) direct LOS conditions between BS and UT antennas. This may be the case for WiMAX installations employing outdoor equipment, where antennas could be mounted high above ground. However, one of the potential benefits for deploying WiMAX systems is the possibility of using self-installable desktop/portable indoor terminals. For these terminals it would be more appropriate to use some non-LOS propagation prediction model like the ones used for mobile services and, eventually, also to account additionally for wall penetration losses.

Most of the traditional path loss models developed for cluttered mobile environment (e.g. Okumura-Hata, Walfish-Ikegami, etc) are valid for traditional mobile services bands below 2-3 GHz and therefore are not suitable for our purposes. But recently a European WINNER research consortium has developed a new propagation model that is suitable for mobile environment at frequencies between 2-6 GHz [8]. This makes it suitable for using in predicting non-LOS propagation for WiMAX FWA type of services in the considered here 3.5 GHz band.

WINNER model is split to several expressions depending on what type of coverage cell is considered, and our case of rural coverage would correspond to WINNER model‘s definition of „D1-rural macro-cell“. For non-LOS propagation modelling for this case, the WINNER model offers the following expression:

$$L_{WINNER-D1}^{NLOS} = (55.4+25.1\log(d)-0.13\log(h_{BS}-25))\log(d/100) -0.9(h_{UT}-1.5)+21.3\log(F/5.0). \qquad (3)$$

For LOS conditions in rural macro-cells, the WINNER model offers the following conditional expression:

$L_{WINNER-D1}^{LOS} = \{$

Option 1: for 10 m $< d < d_{BP}$:

$L=21.5\log(d) + 44.2 + 20\log(F/5)$,

Option 2: for $d_{BP} < d <$ 10 km:

$L=40.0\log(d)+10.5-18.5\log(h_{BS})-18.5\log(h_{UT})+1.5\log(F/5)\}$, (4)

where $d_{BP} = 4h_{BS}h_{UT}f/c$.

In both (3) and (4) d is distance in m, F is frequency in GHz, and h_{BS}, h_{UT} are the heights of respectively BS and UT, m above ground. Equation (3) is verified for distances up to 5 km [8], while (4) is verified up to 10 km.

Below Fig. 1 depicts the plots of both FSL and the two WINNER-D1 models.

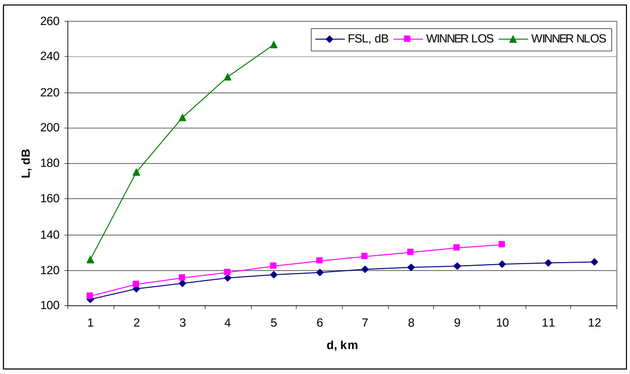

Fig. 1. Comparison of FSL vs WINNER-D1 model results (f=3.5 GHz, h_{BS}=30 m, and h_{UT}=3 m)

Comparison in Fig. 1 reveals that WINNER LOS model is just moderately modifying the FSL predictions, up to some 10 dB at 10 km, however this might also prove an important difference for realistic (i.e. erring on pessimistic side) predictions. Therefore it might be proposed to consider further only the two curves of the WINNER-D1 model.

Considerations of range vs offered bitrate

As already mentioned previously, the maximum bitrate offered to a particular UT will depend on the modulation state of the BS signal, which in turn depends on the signal-to-noise ratio, and through that it becomes dependant on distance between UT and BS. In reality, the WiMAX BS is expected to have „coverage rings”, as shown in Fig. 2.

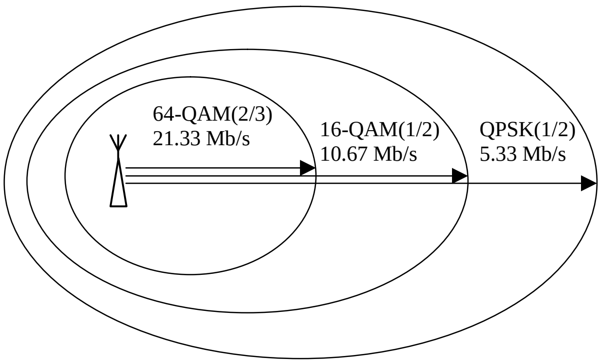

Fig. 2. Coverage „rings“ of WiMAX BS [6]

While the concept of coverage rings is well explained in many sources, the question of how far exactly those rings extend remains open as it depends on the particular propagation environment. Further in this paper we analyse this issue for the considered case of rural cell.

In order to derive the extent of coverage for particular modulation state, one has to compare the received signal strength against the sensitivity threshold established for WiMAX receiver in each modulation state.

With reference to [2], it is possible to establish the range of required sensitivity vs modulation state as given in Table 1. Note that only three out of 6 possible states of physical WiMAX-OFDMA interface are given as a way of example; the values are applicable to 20 MHz channelling option.

Table 1. WiMAX sensitivity threshold vs modulation [2]

Modulation state	Sensitivity threshold, dBm
64-QAM(2/3)	-66
16-QAM(1/2)	-73
QPSK(1/2)	-80

Note that besides sensitivity, another important factor defining the choice of modulation state will be the actual SINR value observed by receiver. However in the considered case of stand-alone rural cell we may assume that there is no external co-channel interference present in the system, as e.g. would be the case for a cell being part of extended (urban) cellular structure. Therefore we may just refer to sensitivity threshold as the only defining criterion in this case.

Substituting the values of minimum received power from Table 1 into the link budget formula and solving it for the minimum path loss should allow linking the modulation state to a particular achievable link distance. A typical link budget formula might look:

$$p_{rx}=P_{tx} + G_{tx} + G_{rx} - L(f,d) - \delta, \qquad (5)$$

where p_{rx} is the received signal power, dBm, P_{tx} is the transmitter output power, dBm, G_{tx} and G_{rx} are gains of transmitter and receiver antenna respectively, dBi, $L(f,d)$ is propagation loss, dB, that is function of frequency and distance, and δ is a random component, dB, that represents fading variation of the signal in multipath environment.

Solving (5) for L would allow us evaluating maximum allowed path loss as a function of given p_{rx} threshold:

$$L(f,d)^{max} =P_{tx} + G_{tx} + G_{rx} - p_{rx}^{thr} - \delta \ . \qquad (6)$$

In this expression a certain maximum value assigned to δ would act as a “fading margin” when evaluating maximum allowed path loss. WINNER evaluations showed [8] that the typical rural deployment would have fading with standard deviation in the order of σ=6…8 dB, and assuming normal distribution of the slow-fading signal it may be suggested to use the 2*σ-rule and set δ=14 dB to obtain 95% coverage certainty.

When choosing other values for parameters in (6), one may further observe that G_{rx} will depend on the type of installation, e.g. portable UT will have an antenna of 0…3 dBi, whereas externally mounted UT may have directional antenna with gain in the order of 10 dBi. Furthermore, consideration of indoor deployment would call for considering some additional wall penetration loss, but we may again disregard this factor in the case of rural cell, as one might imagine that a remote user will be willing to place even a portable indoor UT somewhere near the window to improve the reception. With these considerations and assuming the remaining parameters to be: P_{tx} = 35 dBm, G_{tx} = 17 dBi, as well as the values of p_{rx}^{thr} taken from Table 1, it is possible to derive the values for maximum tolerable path losses for different modulations, as given in Table 2.

Table 2. Derived tolerable path loss values

	Tolerable path loss, dB		
Type of UT	**64-QAM**	**16-QAM**	**QPSK**
Portable (G_{rx} = 3 dBi)	107	114	121
Outdoor (G_{rx} = 10 dBi)	114	121	128

Solving the path loss models (3) and (4) for the tolerable path loss values given in Table 2 would generate the maximum link distance for given modulation state, as given in Table 3.

Table 3. Derived maximum link distances (WINNER-D1)

	Maximum link distance, km		
Type of UT	**64-QAM**	**16-QAM**	**QPSK**
Portable – NLOS model	0.75	0.85	0.95
Outdoor – LOS model	2.5	4.75	7

Analysing results given in Table 3 one could clearly see that even in rural environment the WiMAX communication range for NLOS coverage might not be very significant, compared with the expected overall cell radii in the order of 10 km or more. Therefore it may be recommended that outdoor UTs should be the preferred choice for longer range rural deployments.

Economic considerations

In the case of rural deployment of a remote singular cell, the issue of economic viability becomes especially important, as the costs of deploying a cell must be off-set by the revenues generated solely by subscribers within that cell, as opposed to urban cells where a degree of roaming incomes might be foreseen. However the self-recovery principle may be mitigates in some cases by a certain degree of cross-financing across a larger network or, possibly, universal service funding could be made available to offset part of the costs.

To consider whether economic sustainability would be a problem, it might be suggested to use the standard Net Present Value (NPV) method that would establish the present value of investments against future incomes and costs over N years as follows:

$$NPV = -I_0 + \sum_{i=1}^{N} \frac{R_i - C_i}{(1+IR)^i}, \qquad (7)$$

where I_0 represent initial investments (CAPEX), R_i and C_i – net revenues and operating expenditures (OPEX) respectively in year i, and IR an appropriate interest rate.

In the considered case, it may be suggested to use rather small N, of 3-5 years, as any longer pay-back period may be compromised by rapidly changing technology and competition. Therefore we shall further assume N=3.

Regarding the other parameters in (7), the CAPEX may be roughly estimated for WiMAX BS to be in the order of 75 000 USD (180 000 Lt), of which 2/3 for equipment and installation and 1/3 for backbone connection. Regarding the annual OPEX, we may assume that the cell would be maintained as a part of the overall (national) network, therefore maintenance costs would be spread across the network and may be evaluated by taking some typical proportion of revenues for well established network [3], e.g. 11% for marketing and customer service, 7% for maintenance service, 5% for spare parts, and 3% for general administration. Thus we assumed that total OPEX value would be 26% of revenues. Corporate tax rate of 15% was applied to profits.

When considering future revenues, it may be suggested that for this service to be attractive and affordable to broader rural population in this country, the basic monthly offering should be in the range of 50 Lt a month (ca. 20 USD/month). Such fee may be linked with the bitrate offering of 1-2 Mb/s, which as was shown before, would be also technically sustainable at the greater distances throughout the cell. The operator may also have some higher bitrate offerings for businesses or private "power users" at, say 200 Lt a month. It is then reasonable to assume a typical 10:1 ratio between residential and business users. We do not account for price of user terminals assuming that these may be leased to subscribers or proportionally added to the monthly subscription fee.

Based on all of the above assumptions, we then calculated NPV estimates at 5% interest rate for three scenarios of number of users: pessimistic (25 residential users 1st year, 50 users from 2nd year on), moderate (25, 50, 100 users for years 1-3) and optimistic (50, 100, 150 users for years 1-3). The results are given in Table 4.

Table 4. NPV (*IR*=5%) results for different use scenarios

Usage scenario	**Pessimistic**	**Moderate**	**Optimistic**
NPV in 3 years, kLt	-120	-97	-38

Considering results given in Table 4, it may be concluded that the business case for a single WiMAX cell deployed in rural area has a significant risk of providing negative return on investments in the shorter term, even for most optimistic service uptake scenarios.

Overall conclusions

Technical and economic analysis of deploying a single WiMAX cell in remote scarcely populated areas shows that such deployment would have to cope with significant challenges, both technically and economically. Therefore it may be recommended that operators perform a very careful evaluation of technical plans and business case before such deployment is considered.

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A. Medeišis. Techno-economic Case for a Remote WiMAX Cell // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 5(85). – P. 61–64.

This paper provides technical and economic analysis of deploying a stand-alone WiMAX cell in remote scarcely populated areas. First it considers the technical aspects of sufficient capacity as well as range, and concludes with reviewing the economic viability using NPV method. The analysis shows that such deployment would have to cope with significant challenges, both technically in terms of maximum range and economically in terms of risk of negative return on investments in the short term. Ill. 2, bibl. 8 (in English; summaries in English, Russian and Lithuanian).

А. Медейшис. Техно-экономический анализ удаленной соты WiMAX // Электроника и электротехника. – Каунас: Технология, 2008. – № 5(85). – С. 61–64.

Рассматриваются технические и экономические аспекты, связанные с развертыванием одиночной соты WiMAX в условиях удаленной малонаселенной территории. В техническом плане рассматриваются вопросы абонентской емкости и обеспечиваемой дальности связи, а в экономическом плане рассчитывается возможность окупаемости инвестиций методом NPV. Представленный анализ показал, что развертывание WiMAX сот в малонаселенных районах связано с большими техническими трудностями по обеспечению желаемой дальности и риском финансовой убыточности. Ил. 2, библ. 8 (на английском языке; рефераты на английском, русском и литовском яз.).

A. Medeišis. Techninė-ekonominė WiMAX ląstelės analizė // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 5(85). – P. 61–64.

Nagrinėjami techniniai ir ekonominiai klausimai, susiję su pavienių WiMAX ląstelių diegimu nutolusiose ir mažai apgyventose (kaimo) vietovėse. Techninėje plotmėje analizuojama ląstelės talpa bei ryšio aprėptis, o ekonominėje plotmėje grynosios dabartinės vertės (NPV) metodu įvertinama investicijų grąžos perspektyva. Pateikta analizė rodo, kad toks atskirų WiMAX ląstelių diegimas kaimo vietovėse apsunkins užtikrinti norimą ryšio nuotolį ir sukels didelę finansinę riziką trumpu laikotarpiu. Il. 2, bibl. 8 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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