WiMAX, an uncertain promise for bridging the Digital Divide

Carlos Rey-Moreno,Javier Simó-Reigadas and Andrés Martínez-Fernández
{carlos.rey, javier.simo, andres.martinez}@urjc.es
Universidad Rey Juan Carlos, Signal Theory and Communications Department
Camino del Molino s/n, Fuenlabrada, 28943, Spain
Tel: +34914888463 Fax: +34914887500

1. Introduction

In general terms, technology is born as the indirect consequence of social demands that are identified by researchers as interesting problems to solve; in solving the problem, they produce new knowledge. If they think they will obtain benefits, manufacturers and service providers take those results and produce products and services that satisfy that demand. Undoubtfully, there exist social needs that cannot be covered obtaining benefit. If a society considers covering those needs to be a social priority, then complementary measurements should be taken to adequately promote innovation.

In ICT (Information and Communication Technologies), innovation tends to satisfy the needs of urban inhabitants because they are more concentrated and richer than those living in rural areas. It also tends to privilege the needs of people living in developed countries, where the number of consumers for new products and services is much higher. Access to ICT becomes more and more relevant as we evolve towards a new society structured around information and knowledge. The different access to ICT is not only important by itself, but also it creates significant differences in the access to quality healthcare, educational resources, and markets. This gap in global opportunities, that becomes wider because of different access to ICT, is generally called the Digital Divide, and exists among countries as well as between urban and rural areas within each country. Bridging this gap may improve the access to primary services and, hence, foster human development.

A technology called WiMAX was born in 2001 as a wireless alternative to xDSL technologies for last-mile residential Internet access, but also as a means to bring connectivity to undeserved areas. WiMAX is considered by many experts as having the main features for bridging the Digital Divide existing both in urban areas of developing countries and in rural areas of the World [10, 27]. Nevertheless, almost ten years after its release, it does not seem that WiMAX has fulfilled this aim.

Hence, an existing appropriate technology is not satisfying the needs of an existing demand. This article analyses the reasons for this failure in the improvement of social development through technology.

2. Understanding the relationship between WiMAX and the Digital Divide

2.1 WiMAX basics

WiMAX stands for “Worldwide Interoperability for Microwave Access.” Although many people refers to it as a technology, it is actually only the name of the interoperability certificate given to devices compliant with the IEEE 802.16 standard. The first preliminary version of the standard was released in 2001, and since then several updates and amendments have taken place. The first applicable standards of this family were IEEE 802.16d-2004 and IEEE 802.16e-2005, informally known as fixed and mobile WiMAX respectively. Those standards and the amendments that followed have been finally integrated in the current full version, IEEE 802.16-2009, that was approved in May 2009. Although it is not strictly correct, WiMAX will be used as a synonym of the standards name for a simpler understanding in this paper.

WiMAX was created for providing a wireless alternative for last mile access in metropolitan area networks. The standard only describes the physical (PHY) and medium access control (MAC) layers, permitting this technology to be compatible with all-IP infrastructures used worldwide. WiMAX defines networks formed by a device called a base station (BS) that centrally manages several subscriber stations (SS) or mobile stations (MS) within its range of coverage. In this topology, the BS distributes wireless resources among the different SS based on the Quality of Service (QoS) requirements of the services provided by the network. Based on a Grant/Request mechanism and a tight scheduling, the BS allocates time and frequency slots to each SS for meeting those QoS requirements, while avoiding collisions among SSs. Although some other aspects of the mechanisms defined in the standard are extremely detailed, the design of the schedulers has been left open and are, therefore, vendor specific.

The standard also defines the frequency bands within which the network may operate, and the modulation schemes to be used in each of them. It introduces Single Carrier (SC) modulation for communication in frequencies from 10 to 66 GHz in scenarios where there is line of sight (LOS) between the transmitter and the receiver; and Orthogonal Frequency Division Multiplexing (OFDM) for communications it frequencies from 2 to 11 GHz, including licensed and license-exempt bands, and scenarios without line of sight (NLOS). OFDM can be combined to two different multiple access modes for SSs to share the uplink channel: SS tranmiting at different times, known as Time Division Multiple Access (TDMA) and SS transmiting at the same time in different frequencies (OFDM subcarriers), known as Orthogonal Frequency Division Multiple Access (OFDMA). While the former performs well in fixed scenarios, OFDMA suits better for mobile communications.

In addition to this, two different mechanisms are described for separating uplink and downlink traffic TDD (Time Division Duplexing) and FDD (Frequency Division Duplexing). TDD uses the same channel sequentially for both the uplink and the downlink, while FDD uses different frequencies for uplink and downlink simultaneously. As the traffic exchange in access networks use to be highly asymmetrical, TDD uses much more efficiently the only channel employed and hence has been generally adopted.

Another feature of the WiMAX technology is that the BS dynamically adapts the modulation schemes used by the SS based on channel quality: as the channel quality changes, modulation and coding are dynamically changed to ever have the best possible performance. This allows longer range communications at the cost of lower performance. Out of the link budget, there are no intrinsic limits regarding the maximum distance that WiMAX can be effective.

The standard also includes the possibility of incorporating advanced capabilities such as multiple input multiple output (MIMO), adaptive antenna systems (AAS), and beam-forming, all of which can improve the performance of a WiMAX network.

2.2. The WiMAX ecosystem

Several actors participate in the cycle of creating, producing and applying WiMAX solutions. These are the people who define the current state of the technology. These actors constitute an "ecosystem" within which WiMAX systems evolve. To understand the implications of this ecosystem, we need to examine who its "citizens" are and the relationships among them.

The standard governing body in WiMAX is the IEEE 802.16 Working Group. That groupis in charge of defining the technical specifications of the technology, through both amendments and revised version of the standard, and assuring that it is theoretically feasible. It is composed of members of the most prominent vendors in the telecommunication industry such as Motorola, Samsung, and Intel, and some researchers from private institutions.

However, the Working Group sometimes leaves some aspects incompletely defined in the standard. When this occurs, the research community works to provide solutions to those problems incompletely addressed in the standard.

Their results are sometimes included or at least considered in the final solutions that manufacturers implement in their devices. The institution in charge of certifying the interoperability among devices from different vendors is the WiMAX Forum, which at the time this paper was written was composed of around 300 members of the WiMAX industry.

Certified WiMAX devices are finally purchased and used by service providers when they decide that these products are useful, profitable, and address their clients' needs. When these devices make use of regulated frequencies, service providers need to acquire a license from national governments to operate in those bands.

It is important to note that the WiMAX Forum decides on the existence of certification profiles. As end users are not represented in the Forum, their interests are not represented when user interests are in conflict with those of the industry.

2.3 What makes WiMAX interesting for reducing the Digital Divide?

The properties that make WiMAX an interesting alternative for reducing the Digital Divide are:

- Fast and cheap deployments. It is a benefit intrinsic to wireless technologies, reinforced in WiMAX by the availability of unlicensed bands.
- Efficient long range data communications: WiMAX has no intrinsic constraints for long distances and it uses adaptive modulation for providing the best data rates possible at each moment. Furthermore, it defines TDD for asymmetric data communications and support for all-IP applications.
- Very flexible technology. It allows operating in wide range of scenarios (LOS or NLOS, fixed or mobile) and in many different frequencies, both licensed and unlicensed.
- Quality of service support and capacity for managing accurately what resources are assigned to each end user. The Grant / Request mechanism together with the multiple access modes defined for avoiding collisions provide this advantage.
- Standard technology. It fosters economies of scale and innovation among the different industry members. It also helps being independent from a single vendor by promoting interoperability among manufacturers.

Given all these benefits, it is surprising that the WiMAX industry has not been able to capture as much attention as expected given the increasing social demands for accessing quality ICTs worldwide. However, decisions taken within the WiMAX industry, coupled with external factors as the appearance of competing technologies seems to explain this situation.

3. Analysing the evolution of WiMAX

3.1 Internal factors that determine how WiMAX is evolving

The strong ecosystem described in the previous section is said to be the cause of successful manufacturing efficiencies that have lead to ever decreasing equipment costs [16].The price of a WiMAX system dropped from 20 000 USD in 2006 [26], to around 5 000 in 2008 [16], to around 1 500 USD today. This has contributed to WiMAX being present in 149 countries through more than 582 operator deployments worldwide [24]. But it is also the cause of taking into account only those WiMAX elements that maximize service providers' revenues as manufacturers maximize their own revenues by adapting their production to service providers' needs.

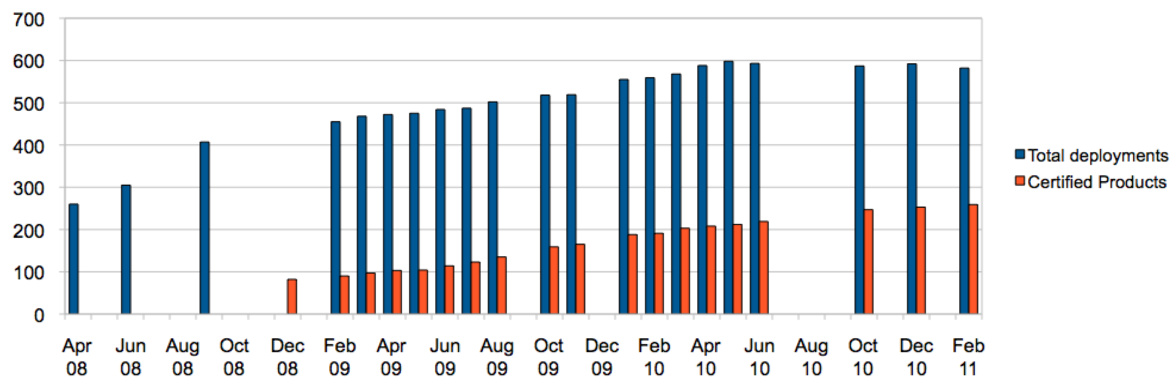
Some solutions that are technically feasible and have prospective benefits for underserved areas have been abandoned or not pushed sufficiently because of a focus on profit-making. As an example, relays, as described in the 802.16j amendment, could be used for improving the coverage and capacity of a network in all kind of scenarios but especially in rural or semi-urban deployments [21]. However, service providers did not show any interest in using them, and so no vendor is interested in manufacturing them [13].

Another solution, the mesh mode, was pointed out by several authors as a solution for rural areas [7, 10]. However, it has been eliminated from the current version of the standard with the official reason given that the mesh standards are incomplete [5]. This occurred despite the fact that a large research community has proposed solutions for making the mesh feasible [11]. Other sources argue that the mesh is not being used because its use could enable users to bypass the middlemen; services providers may be afraid of losing clients and did not push for it, and as a consequence neither did manufacturers [15].

This last argument might help explain the attitude of the WiMAX Forum towards WiMAX operations in license-exempts bands. It is widely acknowledged that the use of these bands will help bridge the digital divide, especially in rural areas [4; 12]. However, although 802.16-compliant products for non-licensed bands are being used worldwide [20] and although vendors have demonstrated interoperability among them [22], the WiMAX Forum is not pushing for the certification of devices for operation in non-licensed bands. This use would reduce business opportunities for service providers and spectrum owners.

As a result, rather than promoting solutions for bridging the digital divide, the WiMAX ecosystem seems to be abandoning those parts of the standards that could contribute to reducing that problem. This is one of the factors that have caused decreasing support for the WiMAX ecosystem. As an example, the number of institutions that have contributed to the specifications of the brand new 802.16m amendment is considerably lower than the number that worked on 802.16-2004 [8], and the growth in the number of both devices and new deployments is slowing down as shown in Figure 1 [24].

Another factor relates to the different policies of national governments regulating the licensed bands in which WiMAX operates; policy differences have prevented uniform worldwide adoption. In addition, given the global economic downturn some governments decided to delay the auctions expecting the crisis to pass away [2], and others increased the bid entrance [19] in order to raise more funds out of spectrum auction for addressing their financial difficulties.



F

iFigure 1: Trends of WiMAX deployments and certifications in the last three years.

3.2 External factors regarding the use of WiMAX in Urban Areas

The use of WiMAX in urban areas comprised a high market share in the WiMAX industry. As every new technology, it is easier to be tested and get higher return on investment (ROI) in a controlled environment where devices are easier to access, and easier to power. Furthermore, population density is much higher and potential clients are richer and more willing to pay for access to information.

The two ranges of frequencies mainly used in WiMAX urban deployments are the ones in the 2 and 3 GHz bands. Non-licensed bands are not usually a good idea in populated areas because interferences reduce the reliability of communications in those bands. Each of those licensed bands has been envisaged for a different purpose: 3 GHz for fixed deployments and 2 GHz for mobile ones. The evolutions of fixed and mobile WiMAX are being conditioned by different external factors and will be analyzed separately.

3.2.1 Fixed WiMAX Evolution

In those places where no previous wired infrastructure exists, WiMAX provides a cheaper and faster last mile access technology that is relatively easy to deploy. This is the case for many developing countries, where greenfield operators have used WiMAX to roll out new networks (Figure 2) in urban and semi-urban areas where no other technologies except satellite were available before.

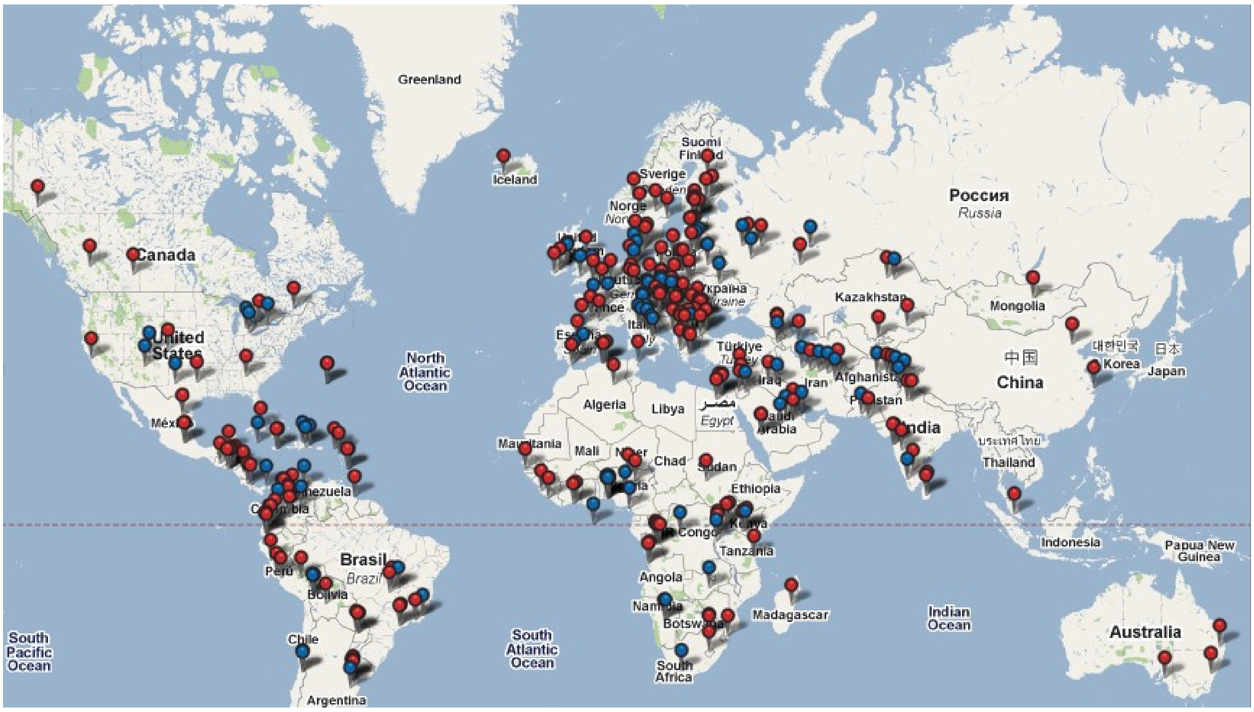


Figure 2: WiMAX deployments in the 3GHz band [25].

The business model of fixed WiMAX operators is generally based on a light infrastructure feeding connections to outdoor customer premises equipment (CPEs). This permits operators to extend coverage progressively at low cost. A much higher density of base stations would permit the use of indoor devices, but the industry clearly does not see any benefit in this possibility for fixed broadband communications. (This observation and latter ones are based on a revision of WiMAX deployments all around the world and interviews with many stakeholders of the WiMAX ecosystem held in the WiMAX World Summit 2010.) Moreover, providers tend to consider the outdoor CPE as an external cost that must be covered by its individual users; hence clients enter into long-term contracts which include the amortization of the subscriber station. These constraints define a product that does not match the needs and possibilities of a majority of households and informal small business in urban areas in developing countries. As a consequence, the demand is low, the number of service providers remains low and the lack of competition keeps prices high, which makes the access to fixed connectivity unaffordable for the underprivileged.

3.2.2 Mobile WiMAX

Mobile broadband seems to be tailored for developed countries where people want to be connected all the time, everywhere. However, there are intrinsic advantages in mobile WiMAX that make it more interesting that fixed WiMAX in many contexts in developing countries as well. The use of USB dongles for residential and nomadic connectivity greatly reduces the cost of additional infrastructure on the client side. Then, operators may explore more flexible products, such as prepaid services, to reach a bigger market share, and thus cover better the existing social demand while maintaining their margins. This compensates the extra costs on the service provider side, since providing mobility services and indoor connectivity to devices with small antennas and little transmission power requires a higher BS density.

There are two families of technologies that can provide mobile broadband: wireless data technologies providing mobility services (WiMAX), and mobile telephony technologies providing data (UMTS, HSPA, EVDO, etc, also known as 3G).

Mobile telephony operators depart from an established ecosystem with a more developed core network, a billing systems in place, and national and global roaming capabilities. Furthermore, in those countries where 2G infrastructure is in place, telephony operators can reuse their towers (although many more are needed), and more importantly, they can reuse their client portfolios, increasing their margins by providing mobile broadband. However, in the last years, they have clearly focused on increasing their 2G coverage in rural areas.

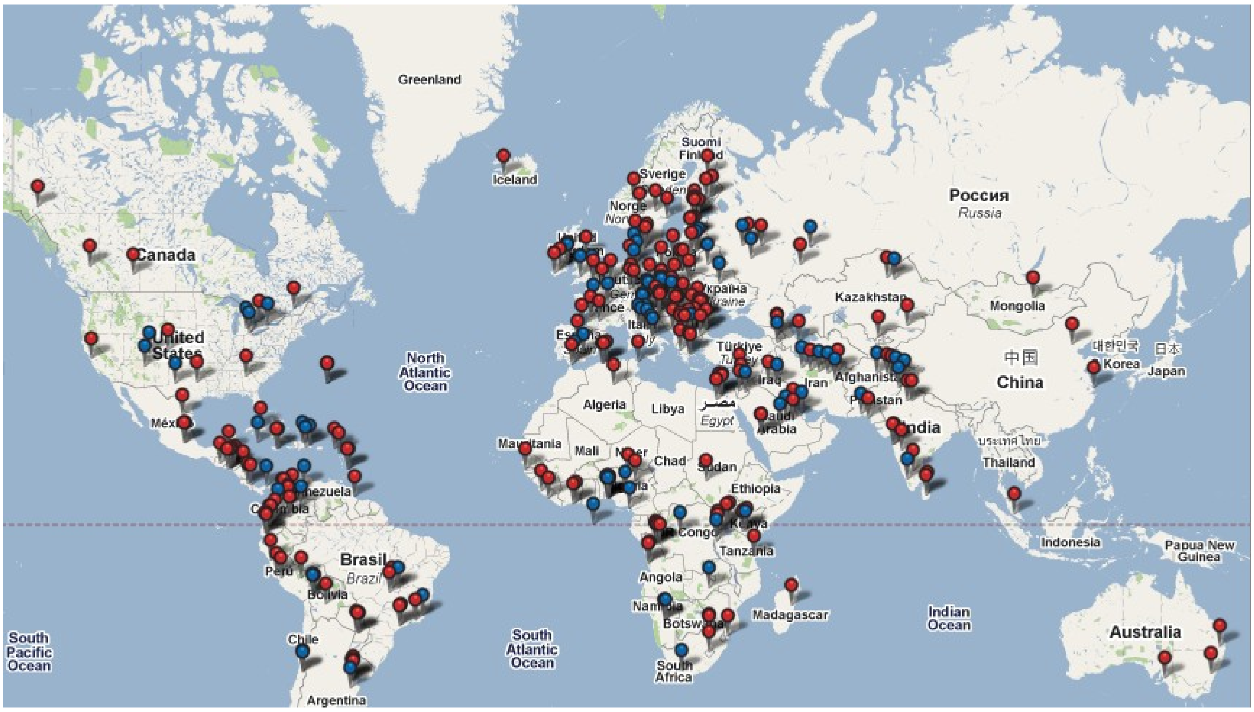


Figure 3: WiMAX deployments in the 2GHz band [25].

Mobile WiMAX operators, on the contrary, can benefit from using an IP-based and TDD technology that can support both voice and data communications in unpaired spectrum, i.e. they only need one channel for both uplink and downlink. Licenses of this kind of spectrum are cheaper than the paired spectrum traditionally used for incumbent mobile telephony operators. In addition to this, it is claimed that it provides better performance than its mobile broadband competing technologies [6]. On the negative side, there are very few user devices for mobile WiMAX as compared to 3G.

New entrants have embraced WiMAX for providing mobile broadband in developing countries (Figure 3). Nevertheless, the economic downturn sharply impacted the raising of capital to build out infrastructure, and the time-to-market advantage of WiMAX disappeared. Mobile telephony operators have started recently to roll out 3G infrastructure with the benefits obtained from its 2G networks. Furthermore, a new disruptive technology has appeared in the market, TD-LTE, that has compromised WiMAX's mobile future. Although, voices from within are pointing to the benefits offered by a proven technology such as WiMAX, both established and new TDD spectrum owners are looking at TD-LTE as their technology of choice [14].

For all these reasons, WiMAX is unlikely to become a solution to the Digital Divide in urban areas of developing countries.

3.3 External factors regarding the use of WiMAX in Rural Areas

3.3.1 General aspects

Since its inception, WiMAX was regarded as the solution for increasing access in rural areas of the world. This idea was followed by a growing interest on the rural operators' side, given the huge market opportunities WiMAX opened for them. However, this has only happened in developed countries where WiMAX has been widely embraced for improving rural access, making use of the 3.5 GHz band. Most of the networks shown in developed countries in Figure 2 correspond to rural deployments. This helps reduce the digital divide among rural people in developed countries. But since 78 % of the world's rural population leaves in developing countries, we will analyze further the case of rural populations in developing countries [9].

Deploying technology in rural areas of a developing country is very challenging due to their intrinsic nature. Their location and, in many cases, the lack of proper roads make them difficult and expensive to reach. In addition, power infrastructure is often deficient and unstable, and in some places nonexistent. This makes the deployment of technology even more difficult and more expensive since an autonomous way of powering the devices is needed. Local technical capacity is often insufficient and in some countries spare parts are not easily found; this hinders the maintenance of the network and raises its operating expenses since both need to be brought from the cities. A final factor is a very sparse population of people who struggle with very tight budgets to spend on non-essential goods, and who lack training in the use of ICTs. These factors combine to make many telecommunication companies (telecos) worried about the potential ROI for deploying in these areas [3].

In this context, the role of governments is paramount. Some propose proper laws for encouraging and supporting telcos to deploy infrastructures in rural areas [23]. Others suggest that local governments should require telcos to free the frequencies they own in the places they are not deploying technology, so that local companies could benefit from using frequencies that propagate better and, thus, reduce costs [1]. However, up to date these kinds of initiatives are not progressing substantially, and the lack of operator investment needs to be compensated with private networks that require alternative technologies.

3.3.2 Comparison of technologies appropriate for this context

Prior to the appearance of the first commercial WiMAX system, other broadband solutions were in place using non-licensed bands, the most popular being WiFi adapted for long distances, and several proprietary technologies derived from it. Urban wireless internet service providers in developing countries were using those solutions where cabled infrastructure was too limited.

The use of high frequency license-exempt bands for relatively long distances implies the need for electromagnetic line of sight between the two sides of a link. To accomplish this, high towers have to be built, autonomous powering infrastructure needs to be installed and electromagnetic protection systems have to be deployed to protect the whole infrastructure [3]. This comprises a great part of the capital expenditure when deploying networks in rural areas. WiMAX operating in non-licensed band has a power consumption similar to alternate technologies. The cost of WiMAX equipment is a bit higher, but the difference is not significant compared to the infrastructure needed.

WiMAX was designed for addressing these challenges which makes it better suited for providing access in rural areas. That is specially the case when there are several places to be connected around a special location, so the point to multipoint topology and the TDMA scheme for avoiding collisions among subscribers proposed by WiMAX offers the best solution. It could also have offered a mesh mode for addressing other scenarios but, as discussed above, this is no longer possible.

Being a technology developed for operators, WiMAX also brings other advantages. QoS allows providing services specially tailored for the communication needs of an area and guarantees that they will be always met. Enhanced security mechanisms also provide WiMAX the opportunity to better address security threats in the wireless channel.

On the one hand, WiMAX is claimed to be more complex, which requires more knowledge for deploying the technology. On the other hand, it provides more robustness, which translates into less effort and lower costs for network maintenance. Some authors also point to the advanced features that WiMAX offers (MIMO, AAS, beam-forming, etc) as a way to further improve performance in rural areas [15]. However, these added features increase the price of the devices and can make the technology less attractive, especially in developing countries, where ROI could be slower.

WiFi has been successfully adapted for long range links. This adaptation has derived in two threads: the adaptation of WiFi for long distances (WiLD), maintaining compliance with the standard [18] and the development of proprietary technologies based on WiFi such as the solutions proposed by Ubiquiti and Mikrotik. These solutions are more limited and deliver less quality than WiMAX, but they are cheap, solid and far easier to configure. When rigid QoS support is not required, WiFi-based systems present significant advantages. The worldwide success of WiFi as a WLAN technology has ensured that the technology is better known, is embedded in almost every laptop and more recently in every smartphone, and that makes it easier to get spare parts.

In terms of quality, it seems that WiMAX should be the technology of choice for bridging the digital divide in rural areas of developing countries. However, there are very few WiMAX experiences that showcase these advantages. The natural market for WiMAX in rural areas is made up of public agencies, rural operators, NGOs and development agencies, but these actors are choosing a combination of WiFi and Wifi-like proprietary technologies to try to overcome the lack of access to information in these areas [17]. Manufacturers of these chosen non-WiMAX solutions are making good profits in this market that WiMAX is neglecting, as pointed in Section 3.1.

4. Conclusion

This paper described the potential of WiMAX for bridging the digital divide. WiMAX has played a role and will continue playing it, but it has not fulfilled the promise held since its inception that it was going to be the key for bridging the digital divide.

In urban areas, the global crisis has attenuated significantly the time to market advantage of WiMAX, allowing the appearance of competing technologies, like TD-LTE, that seem to be becoming the choice of operators worldwide.

In rural areas, the lack of will of the WiMAX ecosystem on pushing further appropriate solutions to address the communication problems in these areas has compromised the success of WiMAX, even though it has many theoretical advantages over its competitors in this field.

This does not mean that WiMAX is going to disappear, as it has a lot of niche markets, but it is difficult to continue holding the promise that it is going to be the solution for bridging the digital divide. This means that some social needs will continue to be unaddressed, even though the appropriate technology to meet them already exists.

References

[1] Association for Progressive Communications, “Opening up spectrum can prevent Kenya from running out”, 2010; http://www.apc.org/en/news/opening-spectrum-can-prevent-kenya-running-out, accessed January 21 2011.

[2] S. Bakhshi, “Analyst Angle: BWA spectrum auction leaves a changed telecom landscape in India, ” in RCRWireless; http://www.rcrwireless.com/article/20100614/SPECTRUM_AUCTION/100619958/1104/analyst-angle-special-edition-bwa-spectrum-auction-leaves-a, accessed February 15 2011.

[3] E. Brewer et al. “The Case for Technology in Developing Regions,” in Computer, 38(6), 25-38, 2005

[4] H. Galperin, “Wireless networks and rural development: Opportunities for Latin America,” in Information Technologies and International Development, 2(3), 47-56, 2005.

[5] V. Genc, S. Murphy, Y. Yu, and J. Murphy, “IEEE 802.16j Relay-based Wireless Access Networks: An Overview,” in IEEE Wireless Communication, 15(5), 56–63, 2008.

[6] D. Gray, “Mobile WiMAX – Part II: A Comparative Analysis. WiMAX Forum White Paper,” 2006;

www.wimaxforum.org/.../Mobile_WiMAX_Part2_Comparative_Analysis.pdf, accessed February 15 2011.

[7] R. Hincapie, J Sierra, and R. Bustamante, "Remote locations coverage analysis with wireless mesh networks based on IEEE 802.16 standard," in IEEE Communications Magazine, 45(1), 120–127, 2007

[8] Institute of Electrical and Electronics Engineers 802.16 Working Group "The IEEE 802.16 Working Group on Broadband Wireless Access Standards"; http://wirelessman.org/, ccessed February 2nd 2011.

[9] International Telecommunication Union, "World Telecommunication / ICT Indicators database"; http://www.itu.int/ITU-D/ict/statistics/, accessed January 21 2011

[10] S. Karanasios, and A, David, "WiMAX for development", in Information Technology for Development, 16(4):320-328, 2010.

[11] P. Mogre, M. Hollick, and R. Steinmetz, "QoS in wireless mesh networks: Challenges, pitfalls, and roadmap to its realization," in ACM Network and Operating System Support for Digital Audio and Video (NOSSDAV 2007), Urbana-Champaign, IL, USA.

[12] I. Neto, M.L. Best, and S.E Gillett, "License-Exempt Wireless Policy: Results of an African Survey," in Information Technologies and International Development, 2(3), 2005

[13] C. Rey-Moreno, "Análisis de la viabilidad de la modificación de la enmienda IEEE 802.16j para su aplicación en la banda no licenciada de 5 GHz". Master Thesis Dissertation, Universidad Rey juan Carlos, Spain, 2010. Available at www.ehas.org/uploads/file/difusion/academico/PFM/PFM_CREYM.pdf [Spanish]

[14] M. Ricknäs, "Devices Key As WiMax Supporter Moves to LTE". CIO, 2010; www.cio.com/article/595209/Devices_Key_As_WiMax_Supporter_Moves_to_LTE, accessed February 28 2011.

[15] E. Sedoyeka, Z. Hunaiti, M. Al Nabhan, and W. Balachandran, "Wimax mesh networks for underserved areas," In AICCSA 2008, Doha, Qatar.

[16] K. Sibanda, H.N. Muyingi, and N. Mabanza, "Building Wireless Community Networks with 802.16 Standard," in Third International Conference on Broadband Communications, Information Technology & Biomedical Applications, Broadcom, 384-388, 2008.

[17] J. Simo, A. Martinez, P. Osuna, S. Lafuente, and J. Seoane, "The design of a wireless solar-powered router for rural environments isolated from health facilities,"in Wireless Communication Magazine, 15(3), 24–30, 2008.

[18] J. Simo-Reigadas, A. Martinez-Fernandez, J. Ramos-Lopez, and J. Seoane, "Modeling and Optimizing IEEE 802.11 DCF for Long-Distance Links," in IEEE Transactions on Mobile Computing, 9, 881-896, 2010.

[19] Sify Finance, "Higher base price for 3G, WiMax auction proposed", 2008; http://www.sify.com/finance/higher-base-price-for-3g-wimax-auction-proposed-news-news-jegrWlcjicj.html, accessed February 15 2011.

[20] Skylight Research, "Unlicensed WiMAX – A Profitable Business Case Often Overlooked," 2008; http://www.apertonet.com/docs/Sky%20Lght%20Research%20-%20Unlicensed%20WiMAX.pdf, accessed February 17 2011.

[21] D. Soldani, and S. Dixit, "Wireless relays for broadband access," in IEEE Communications Magazine, 46 (3), 58-66, 2008.

[22] Tranzeo, "Tranzeo and Aperto Collaborate on WiMax System", 2008; http://www.tranzeo.com/investors/press.php?id=82, accessed February 17 2011.

[23] B. Wellenius, "Closing the gap in access to rural communications: Chile 1995-2002," in Info, 4(3), 29 – 41, 2002.

[24] WiMAX Forum, "Monthly Report Archive", 2011; http://www.wimaxforum.org/resources/research-archive, accessed February 2 2011.

[25] WiMAX Forum, "WiMAX Deployments", 2011; http://www.wimaxmaps.org/, accessed February 2 2011.

[26] A Yarali, B. Mbula, and A. Tumula, "WiMAX: A key to bridging the digital divide,", in Proceedings IEEE SoutheastCon, 159-164, 2007.