

WMAN@FES

Comparison of Fiber and Wireless Technologies

for the implementation of the administrative MAN
of FES, Morocco

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Table of Content

- Introduction 4
 - Context of this study..... 4
 - Methodology 4
 - Architecture of this document 4
- Metropolitan area Networks (MANs) in a Nutshell 4
- Wireless Technologies Available for MANs 5
 - Long Range Wi-Fi..... 5
 - Use of specialized channels and increased multipath protection..... 6
 - Use of MIMO and high gain antennas..... 6
 - Power increase or receiver sensitivity boosting..... 7
 - Protocol hacking..... 7
 - Performance of LR Wi-Fi..... 7
 - Long Range Wi-Fi products..... 8
 - Fixed WiMAX..... 8
 - WiMax products 10
 - Fixed WiMax vs LR Wi-Fi Comparison 10
 - The Application Requirements 11
 - The Wireless Technology Requirements 11
 - The Policy Requirements 13
 - The Costs Requirements..... 14
 - Summary of fixed-WiMAX vs LR Wi-Fi technologies 15
- Optical Fiber networks available for MANs 17
 - Optical fiber: the medium..... 17
 - Optical based Network technologies 19
 - SONET/SDH..... 19
 - WDM..... 20
 - MPLS 21
 - 10GE..... 22
- Fiber vs. Wireless Access Technologies 23
 - Bandwidth 23
 - Installation Costs (CAPEX) 23
 - Operation and Maintenance Costs (OPEX)..... 24
 - Build-out Strategies..... 24

Scalability.....	24
Interference.....	25
Security.....	25
Applications supported.....	25
Legal and Regulatory Issues.....	26
Cooperation between WiMax and 10GE.....	26
Case Study #1 “Bureaux d’Etat Civil” of the City of Fez.....	28
Case Study #2 Hypothetical sub-Saharan African City	33
Background	33
City characteristics	33
Conclusion.....	33
Bibliography.....	34

Introduction

Context of this study

This study is part of the Wman@Fez project that aims at building an administrative Metropolitan Area Network (MAN) for the city of Fez using Wireless technology. Its outcome is not intended to influence the adoption of Wireless technology (specifically Worldwide Interoperability for Microwave Access fixed known as WiMax) for this project; rather, it aims at 1. Providing a quantitative support and comfort the already taken decision of adopting WiMax technology for the Administrative MAN for the city of Fez; 2. Enriching the literature on the question of which is best wireless or Optical fiber for MANs, and 3. Providing a template for the comparison between these technologies in the context of a hypothetical sub-Saharan city in Africa, where connectivity infrastructure is not well developed and both optical and wireless are, a priori, plausible solutions.

Methodology

To produce a fair and balanced comparison between fiber and wireless technologies for MANs, a set of requirements is proposed. The intention behind this is to redirect the question of “which is better?” into a methodological comparison in terms of these requirements. The principal requirements along which it is most instructive to compare fiber-optic and wireless access technologies are **1.** Application requirements; **2.** Technology requirements; **3.** Policy and regulatory requirements; and **4.** Operations and maintenance requirements. Each of these requirements is itself subdivided into a set of criteria. The importance of each requirement and each criterion varies with the context of application.

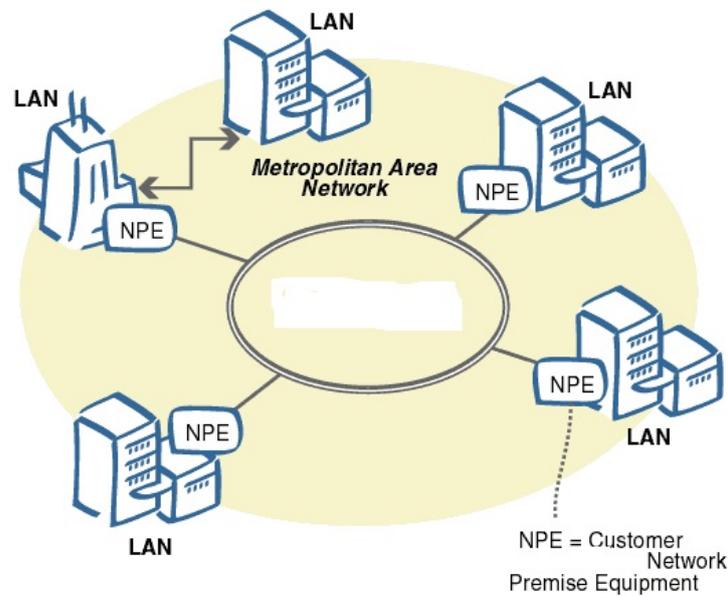
Perhaps it is worth mentioning here that the medium (i.e., optical fiber, radio, coax, twisted pair copper etc.) by itself does not make up for a network/technology. Rather it is the combination of the medium and the active devices (which usually implement one of the networking standards such as IEEE, ATM etc.) that make a technology. Therefore not accurate to speak of optical fiber per say, rather it is more accurate to speak in terms of a technology that uses optical fiber. In what follows, we will try as much as possible not to make the confusion between the medium used to build the network and a the technology that uses the medium.

Architecture of this document

The remainder of this document gives an overview about available wireless technologies for MANs, then makes an intra-wireless comparison between these technologies according to the above cited set of requirements. It then gives an overview about optical fiber medium, and the optical fiber-based technologies for MAN. The decision of adopting a fiber-based or wireless-based technology for a MAN depends heavily on the evaluation of these requirements for each technology in the context of the application domain. As an illustration, we give the details of this evaluation in the case of the implementation of the administrative MAN of the city of Fes. Further, we propose some guidelines for applying such evaluation in the context of an administrative MAN for a hypothetical sub-Saharan city.

Metropolitan area Networks (MANs) in a Nutshell

A metropolitan area network (MAN) is a large computer network that usually spans a city or a large campus. A MAN usually interconnects a number of local area networks (LANs) using a high-capacity backbone technology, such as fiber-optical links (see figure 1), and provides up-link (also called backhaul in the context of a wireless network) services to wide area networks and the Internet.



Typical MAN structure

The IEEE 802-2001 standard describes a MAN as being [1]:

A MAN is optimized for a larger geographical area than a LAN, ranging from several blocks of buildings to entire cities. MANs can also depend on communications channels of moderate-to-high data rates. A MAN might be owned and operated by a single organization, but it usually will be used by many individuals and organizations. MANs might also be owned and operated as public utilities. They will often provide means for internetworking of local networks.

Wireless Technologies Available for MANs

Two major wireless solutions/technologies are available today for building Wireless MANs (WMANs). These are WiMax802.16d a standard-based also called fixed WiMax, and Long range Wireless Fidelity (LR Wi-Fi). Other Wireless technologies, such as 60GHz links and Microwave links, thought providing for very large bandwidths, are not suited for Administrative or city MANs like the one intended for the city of Fez because of 1. Their limited range which usually does not exceed 800m owing to signal decay, and 2. The link type used which, is point to point rather than point to multipoint, does not lend itself to building scalable cost effective medium-size to large wireless networks. In what follows we will give a brief overview of both Long range Wi-Fi and WiMax 802.16d, then we will draw a comparison of these technologies along the set of four (4) requirements namely, **1.** Application requirements, **2.** Technology requirements, **3.** Policy and regulatory requirements, and **4.** Operations and maintenance requirements.

Long Range Wi-Fi

Wi-Fi is the trade name for the popular wireless technology used in home networks, mobile phones, video games and other electronic devices that require some form of wireless networking capability. It covers the various IEEE 802.11 technologies (IEEE 802.11a/b/g/n) also known under Wireless LAN (WLAN), and operates typically either in the **2.4 GHz** or **5 GHz** ISM frequency bands, and supports services similar to those offered by wired LANs (e.g. Ethernet) and can be used to build either stationary or mobile computer networks. A Wi-Fi enabled device such as a personal computer,

video game console, mobile phone, MP3 player or personal digital assistant can connect to the Internet when within range of a wireless network connected to the Internet. The coverage of one or more interconnected access points — called a hotspot — can comprise an area as small as a few rooms or as large as many square miles covered by a group of access points with overlapping coverage. Wi-Fi technology can also be deployed in mesh configuration, resulting in a wireless mesh network allowing for continuous connections and reconfiguration around broken or blocked paths by “hopping” from node to node until the destination (Internet access) is reached. Current WLAN systems provide data rates of typically **54 Mbit/s**, with vendor-specific extensions reaching up to **108 Mbit/s**.

Wi-Fi networks have limited range by design. A typical wireless router using 802.11b or 802.11g with a stock antenna might have a range of 32 m (120 ft) indoors and 95 m (300 ft) outdoors. IEEE 802.11n can exceed double that range. Range also varies with frequency band. Wi-Fi in the 2.4 GHz frequency block has slightly better range than Wi-Fi in the 5 GHz frequency block. In general, Wi-Fi performance decreases roughly quadratically as distance increases at constant radiation levels. Through use of directional antennas within Line Of Sight (LOS), outdoor ranges can be improved. However,

In general, the maximum amount of power that a Wi-Fi device can transmit (and thus the range) is limited by local regulations. For instance the Equivalent Isotropically Radiated Power (EIRP) in the EU and many countries is limited to 20 dBm (100 mW).

While WLAN technologies were not intended for MAN type of networks, many companies deploy wireless MANs using Long Range WLAN standards or Long range Wi-Fi. The Long range Wi-Fi, also known as Wi-Fi over Long Distance (WiLD) in the literature, has been used for instance to connect the Aravind Eye Hospital with several outlying clinics in Tamil Nadu state, India. In there, distances range from five to over fifteen kilometers (3–10 miles). Further extensions of WiLD are expected to feature 80 km point to point links.

To extend Wi-Fi for WLANs to be used for WMANs, Long range Wi-Fi uses a number of techniques. These are use of specialized channels, use of MIMO antennas, use of high gain antennas and protocol hacking. A brief overview of each technique is given below:

Use of specialized channels and increased multipath protection

Long-range Wi-Fi, adds 10 MHz and 5 MHz OFDM modes to the 802.11a standard. It also extends the cyclic prefix protection from 0.8 μ s to 3.2 μ s, allowing for more inter-symbol interference, which in turn increases the multipath distortion protection, allowing for range extension. However, this is done in proprietary way (adds to the 802.11a standard), and at the expense of data rate.

Use of MIMO and high gain antennas

A Long range Wi-Fi for WMANs utilizes high gain outdoor directional antennae to establish a point-to-point links between fixed points in the system. Using dual antennas with orthogonal polarities along with a 2x2 MIMO chipset effectively enable two independent carrier signals to be sent and received along the same long distance path.

Furthermore, specially shaped antennas can be used to increase the range of a Wi-Fi transmission without a drastic increase in transmission power. High gain antenna may be of many designs, but all allow transmitting a narrow signal beam over distances of several kilometers, often nulling out nearby interference sources. "WokFi" techniques use a satellite dish type of antennas and typically yield gains

of 12–15 dB over the bare system—enough for line of sight (LOS) ranges of several kilometers and improvements in marginal locations.

Power increase or receiver sensitivity boosting



A rooftop 1 watt Wi-Fi amp, feeding a simple antenna

Another way of adding range uses a power amplifier. Commonly known as "range extender amplifiers" these small devices supply usually around $\frac{1}{2}$ watt of power to the antenna. Such amplifiers may give more than five times the range to an existing network. Every 6 dB gain doubles range. However, the maximum amount of power that a Wi-Fi device can transmit is limited by local regulations. For instance the Equivalent Isotropically Radiated Power (EIRP) in the EU and many countries is limited to 20 dBm (100 mW).

Protocol hacking

This technique consist in modifying the standard IEEE 802.11 protocol stacks to make them more suitable for long distance, point-to-point usage, at the risk of breaking interoperability with other Wi-Fi devices and suffering interference from transmitters located near the antenna. These approaches are used for instance by the TIER project [].

In addition to power levels, the standard delay for retransmissions due to non-received Acknowledgements is increased.

Packet Fragmentation is also used to improve throughput in noisy/congested situations. Although packet fragmentation is often thought of as something bad, and does indeed add a large overhead, reducing throughput, it improves the throughput in the context of LR Wi-Fi.

Performance of LR Wi-Fi

Obstacles are among the biggest problems when setting up a long-range Wi-Fi. Trees and forests degrade the microwave signal, and rolling hills make it difficult to establish line-of-sight propagation.

In a city, buildings will impact integrity, speed and connectivity. Steel frames partly reflect radio signals, and concrete or plaster walls absorb microwave signals significantly, but sheet metal in walls or roofs may efficiently reflect Wi-Fi signals, causing an almost total loss of signal.

Due to the intended nature of the 2.4 GHz band, there are many users of this band, with as many as 2 or 3 devices per household. By its very nature, "Long Range Wi-Fi" connotes an antenna system which can see many of these devices, which when added together produce a very high noise floor, whereby no single signal is usable, but nonetheless are still received. The aim of a long range system is to produce a system which over-powers these signals and/or uses directional antennas to prevent the receiver "seeing" these devices, thereby reducing the noise floor.

In summary, the use of LR Wi-Fi for metropolitan-sized networks has performance limitations when supporting larger numbers of users needing guaranteed bandwidth. In addition, RF interference is often a significant problem with 802.11 when covering large areas because of license-free operation. Furthermore, the high delay (caused essentially by the CSMA/CS access method used), and the very low throughput and limited distance support in NLOS conditions are many of the drawbacks of LR Wi-Fi. Furthermore, point to point links imposed by the directional antennas limit the use of LR Wi-Fi to modest/small networks.

Long Range Wi-Fi products

Table below shows some of the well known Long range Wi-Fi products compiled at the time this document was being drafted:

Manufacturer	Product
Reliawave	Reliawave™ RWD 5000 Series: http://www.demarctech.com/products/reliawave-rwd/rwd-5000.html
AIRAYA	WirelessGRID: Multipoint Fixed Wireless Bridges: http://www.airaya.com/products/p2m.asp

Known Long range Wi-Fi products

Fixed WiMAX

Worldwide Interoperability for Microwave Access (WiMAX) is a standard-based telecommunications technology that provides wireless transmission of data using a variety of transmission modes including point-to-multipoint. The technology (also called Broadband Wireless Access) provides up to 10 Mbit/s broadband speed without the need for cables. And is based on IEEE 802.16-2004, IEEE **802.16d**, or "*fixed WiMAX*" standard¹. Fixed WiMax systems are meant to provide network access to homes, small businesses, and commercial buildings as an alternative to traditional wired connections.

IEEE 802.16 standard transmits at data rates up to 120 Mbps, and supports point-to-multipoint architecture. At those frequencies, transmission requires line of site, and roofs provide the best mounting locations for base and subscriber stations. The base station connects to a wired backbone

¹ In order to add portability and mobility to the standard, IEEE 802.16 working group initiated the IEEE **802.16e** standard in 2002 for Mobile Broadband Wireless Access. This standard addresses many different mobility issues, including providing connectivity to moving vehicles within a base station's sector, and it is therefore also known as "*Mobile WiMAX*".

and can transmit wirelessly up to 30 miles to a large number of stationary subscriber stations, possibly hundreds.

To accommodate non-line-of-site access over lower frequencies for locations without line of site, IEEE published **802.16a** in January 2003, which includes support for mesh architecture. IEEE 802.16a operates in the licensed and unlicensed frequencies between 2-11 GHz using Orthogonal Frequency Division Multiplexing (OFDM).

The 802.16 MAC layer supports many different physical layer specifications, both licensed and unlicensed. Through the 802.16 MAC, every base station dynamically distributes uplink and downlink bandwidth to subscriber stations using time-division multiple access (TDMA). This is a dramatic difference from the 802.11 MAC, with current implementations operating through the use of carrier sensing mechanisms that do not provide effective bandwidth control over the radio link.

The WiMax Forum has selected three different spectrum bands for WiMax-certified equipment in order to accommodate for a wide variety of regulatory regimes. Those three spectrum includes 2.5 GHz, 3.5 GHz and the licence exempt spectrum at 5 Ghz.

WiMAX not only avoids the main disadvantages of industry standards, but also is set to deliver powerful advantages. With worldwide endorsement of WiMAX and proven equipment interoperability, the business case for WiMax from a provider point of view is, now as this report is being written, beyond any doubts. Indeed, the standard provides a range of compelling benefits to all players in the industry value chain. Some of these benefits are summarized below:

Supplier	Equipment Manufacturers	Operators and Service Providers
<p>Assured wide market acceptance of developed chips and components,</p> <p>Lower production costs due to economies of scale,</p> <p>Reduced risk due to interoperability</p>	<p>Stable supply of low-cost components and chips</p> <p>Freedom to focus on development of network elements consistent with core competencies, while knowing that equipment will interoperate with third-party products</p> <p>Engineering development efficiencies</p> <p>Lower production costs due to economies of scale</p>	<p>Lower CAPEX – with lower cost base station, customer premises equipment (CPE), and network deployment costs</p> <p>Lower investment risk due to freedom of choice among multiple vendors and solutions</p> <p>Ability to tailor network to specific applications by mixing and matching equipment from different vendors</p> <p>Improved operator business case with lower OPEX</p>

Benefits of Wimax across the value chain

This said, the business case for WiMax as technology for small scale networks, outside of the operator arena, such as the administrative MAN of the city of Fez is not confirmed given the relative importance of the various requirements defined earlier and their sub-criteria (see comparison section).

From a technical point of view, the following table summarizes the strengths and weaknesses of WiMax technology.

WiMAX strengths	WiMAX weaknesses
<ul style="list-style-type: none"> • Point to Multipoint: A single WiMAX station can serve hundreds of users • Much faster deployment of new users comparing to wired networks • Speed of 10 Mbps at 10 kilometers with line-of-site • Supports Non line of Sight • It is standardized, and same frequency equipment should work together • Short delay 	<ul style="list-style-type: none"> • Line of site is needed for (+10km) links • Weather conditions like rain could interrupt the signal • Other wireless equipments could cause interference • Multiplied frequencies are used • WiMAX is very power intensive technology and requires strong electrical support • Big installation and operational coast

WiMAX strengths and weaknesses

WiMax products

Table below gives some of the major WiMax manufacturers on the market at the time of writing this document:

Manufacturer	URL
Airspan	www.airspan.com
Redline	www.redline.com
Proxim	www.proxim.com
Aperto	www.apertonet.com/
Alvarion	www.alvarion.com

Major fixed-WiMAX manufacturers

Fixed WiMax vs LR Wi-Fi Comparison

In general, the question of which technology is best can only be answered given an application/project context. As stated in the introduction of this document, it is also a common practice to express a set of requirements against which the technology is evaluated. These can be regrouped into the following:

The Application Requirements

These are factors that directly have an impact on the Quality of Service for applications that will run on top of the WMAN or their security. Common applications are:

1. Voice-over-IP (Internet telephony) (sip, iax2)
2. Video conferencing (h.323)
3. eGov application (http) (in the context of WMan@Fez project)
4. Web (http, https)
5. Mail ((secure) pop3, imap, smtp)
6. Network monitoring applications (snmp, icmp)
7. Internet and authentication services (dns, netbios etc.)
8. Database query (ODBC)

Video Conferencing in particular, is the most bandwidth demanding and time-stringent application. The data is first encoded into one audio and one video stream using a certain encoding rate (kbps). The two streams are then compressed and sent out towards the receiver. The compression efficiency depends highly on the motion of the video as it removes redundant information. A video conference with very little motion, for example a person sitting still talking, can be compressed to 50% of the required bandwidth. The higher encoding rate used, the better quality of the video. However, the bandwidth requirement of the network increases proportionally with the increase in encoding rate. To achieve a similar visual quality as a TV can provide, a transmission rate of no less than 30 frames/sec is needed². That frame speed corresponds to an encoding rate of 384 kbps and a minimum bandwidth of less than 384 kbps (due to compression).

VoIP application on the other hand requires 95 kbps³ per call in the worst case scenario (G.711 and SIP). Table below shows some bandwidth requirements for some major VoIP codecs.

Codec	Bandwidth	Sample period	Frame size	Frames/ packet	Ethernet Bandwidth
G.711 (PCM)	64 kbps	20 ms	160	1	95.2 kbps
G.723.1A (ACELP)	5.3 kbps	30 ms	20	1	26.1 kbps
G.723.1A (MP-MLQ)	6.4 kbps	30 ms	24	1	27.2 kbps
G.726 (ADPCM)	32 kbps	20 ms	80	1	63.2 kbps
G.728 (LD-CELP)	16 kbps	2.5 ms	5	4	78.4 kbps
G.729a (CS-CELP)	8 kbps	10 ms	10	2	39.2 kbps

Ethernet Bandwidth requirements for SIP/RTP for different codecs

The requirements for VoIP is symmetrical for downlink and uplink as a conversation is bi-directional. By using SIP native bridging, media traffic can travel the shortest path between two clients and does not need to go through the softswitch in a P2P fashion.

The Wireless Technology Requirements

These are issues regarding availability, frequency, price and other factors related to selection of the technology itself. The wireless technology requirements are concerned with:

² Video Conferencing, <http://www.at.northwestern.edu/ctg/videoconf/H323basics.html>

³ VoIP bandwidth calculator <http://www.newport-networks.com/whitepapers/voip-bandwidth3.html>

Supported network topology

Technologies that do not support point to multipoint are not scalable in a cost effective approach, and add extra burden/cost in network management.

Support for NLO

Non (or Near) Line Of Sight is an increasingly important feature required for Urban wireless networks, as it is difficult to obtain line of Sight between all sites of the Network. When not supported it can make the whole wireless option not viable.

Power consumption

This is the amount of power consumed by a wireless active equipment (which can be a base station or a Master unit, or a client unit –CPE-) during normal operation. If the wireless unit needs to be powered by solar energy, a low power consumption is preferable. In such cases, it is recommendable that equipment accept a DC Input voltage (12, 24 or 48 V) in order to avoid DC/AC power conversion

Effective Isotropic Radiated Power (EIRP)

The effective power sent out from a system taking into consideration the losses in cables and connectors and the gain of the antenna. The Maximum Radiated Power is regulated by the national radio regulatory authority and specifies the maximum power that is legally permitted to be sent out to the free air in a specific country/area. For instance the Equivalent Isotropically Radiated Power (EIRP) in the EU and many countries is limited to 20 dBm (100 mW).

Antenna characteristics: Gain and Beam width

An antenna is a transducer designed to transmit or receive electromagnetic waves. Gain and beamwidth are characteristics of an antenna. The antenna gain is the measurement of the increase of the transmitted signal in a given direction with respect to the very same signal transmitted by an isotropic antenna. It is measured in dBi. The beamwidth represents the amplitude where the antenna transmits most of the power. The beamwidth is measured with two angles vertical (V) and horizontal (H). In the edges of this angles, the power is half of the maximum (-3 dB). To meet the EIRP regulations, and deliver maximum throughput, wireless units will require high gain antennas. Link budget calculations are often used to work out the antennas' gain, and beamwidth.

Backhaul and CPE units should use highly directive antennas (low beamwidth) in order not to add unnecessary noise to the spectrum.

Antenna diversity

Antenna diversity is a transmission technique in which the information-carrying signal is transmitted along different propagation paths. This can be achieved by using multiple receiver antennas (diversity reception) and/or by using multiple transmitting antennas (transmit diversity)⁴. Although the advantages of antenna diversity are several, its benefits are most obvious in situations where clients are widely spread in terms of distance and angle or when they are mobile.

⁴ Wikipedia: http://en.wikipedia.org/wiki/Antenna_diversity

SNR

Signal to Noise Ratio, the power ratio between a signal (actual information) and the background noise. SNR is improved by:

1. Incrementing of Signal level in the CPE by means of high gain antennas.
2. Avoiding the use of RF amplifiers
3. Clearing at least 80% of the first Fresnel zone. (for a 10km link in 5.8GHz, 80% of the Fresnel zone is 9 meters⁵).
4. Using low transmission power in the client

Frequency of operation

A system that operates in a frequency that does not attenuate due to rain, fog and clouds. The system/ technology should operate in a frequency < 10 GHz.

DFS (Dynamic Frequency Steering)

The ability to detect signals that must be protected against 5GHz interference, and upon detection switch the operating frequency to one that is not interfering with the detected signal. As a result of the increased availability of unlicensed 5-6 GHz spectrum and the steadily increase of equipment operating in this range, there is a need of coordinating the frequency allocation between actors operating within the same range. This need has resulted in the adoption of DFS (dynamic frequency steering) as a required feature of radio products operating in the certain spectrum. Europe, as of July 2005, requires DFS for any 5-6 GHz product before being granted ETSI approval. In the US, DFS is required starting 2008 for any new products which are sold.

TPC (Transmitted Power Control)

The ability of adapting the transmission power based on regulatory requirements and range information. The idea of Transmitted Power Control is to automatically reduce the transmission output power when other networks are present within the same range. Reduced power implies not only reduced interference, but also decreased power consumption. The selected equipment should have support for TPC (assuming that the frequency of operation is within the 5 GHz range).

The Policy Requirements

These are requirements that the decision making actors of the project (Wman@Fez in this particular context) have set up to follow in regards to openness, frequency spectrum, interoperability, certification etc.

Frequency

The unlicensed 2.4 GHz band is noisy in urban areas due to the high penetration of low cost indoor wireless and the presence of other devices that are communicating in the same frequency. The 5 GHz band gives the advantage of less interference but faces other problems due to its nature. High frequency radio waves are more sensitive to absorption than low frequency waves. Waves in the range of 5 GHz are more sensitive to water and surrounding buildings or other objects due to the higher

⁵ Fresnel Zone Online Calculator <http://www.terabeam.com/support/calculations/fresnel-zone.php#meters>

adsorption rate in this range (e.g. tree absorption ranges between 0.25-0.5 dB/m in 2.4 GHz and 0.5-1.5 dB/m in 5.8 GHz).

While the 2.5 GHz and 3.5GHz bands require costly licences and are mainly allocated for major operators, the 5GHz band is either unlicensed or require a “light licence” and is hence more

Band	Frequency (Ghz)	Maximum Power (US/ Europe)
European Band	5.470-5.725	200 mW (Indoor/ Outdoor) 1 W (Indoor/ Outdoor)
UNII 1	5.150-5.250	50 mW (Indoor) 200 mW (Indoor)
UNII 2	5.250-5350	200 mW (12.5 mW/ Hz) (Indoor/ Outdoor) 200 mW (Indoor)
UNII 3	5.725-5.825	800 mW(50 mW/ Hz) 25 mW

Frequency range and maximum transmit power for the 5.x GHz ISM UNII bands

appropriate for so called “grass roots” ISPs. Therefore, the network should operate in a frequency range that is unlicensed (or light licensed) which does not suffer severely from interference. For both WiFi and WiMax, the preferable frequency of operation is within the 5.150-5.825 GHz range. 1 W EIRP is allowed in the 5.470-5.725 range⁶.

Interoperability

This is the ability of two or more systems or components to exchange information and to use the information that has been exchanged⁷. Selected equipment should be inter-operable with other products of the same technology. If certification is not available, experiences with other CPEs and vendors is recommended.

Openness

In the sense of being compliant with open standards for radio communication. The selected equipment should follow open standards for radio communication and provide a minimum amount of proprietary features for additional services beyond what the open standard provides.

Certification

The procedure by which a third party that is, neither the provider nor the customer gives written assurance that a product or service conforms to specific requirements. When possible the selected equipment should be certified by a major forum such as the WiFi Alliance or the WiMAX Forum.

The Costs Requirements

⁶ I-ETS 300 440 "Radio Equipment and Systems (RES); Short Range Devices (SRDs); Technical characteristics and test methods for radio equipment to be used in the 1 GHz to 25 GHz frequency range.

⁷ Definition of Interoperability by IEEE.

This set of requirements is concerned with both installation and operations and maintenance costs, commonly called OPEX and APEX.

Installation costs

This refers to the cost of the active equipments (CPEs, BSs) together with the accessories costs (arresters, masts, poles etc.) and the cost of engineering (that is configuring the devices)

Lighting arresters are protective devices for limiting surge voltages due to lightning strikes or equipment faults. Base stations and CPE should include data and power lightning arrestors. Include CAT5/6 Data Line Lightning and Surge Protectors. If external antennas are used, Coaxial Gas Discharge Tube Lightning and Surge Protectors need to be included.

The cost of Masts or poles can put a heavy burden on the project. In general the height parameter is included in the link budget calculations.

Operations and maintenance costs

There are additional cost factors that are recurring beyond the initial installation costs. The cost of spectrum, and the rental of space on some tall structure are such costs. To offset this cost, some providers have entered into creative partnership agreements with the owner of the tall structure, whereby the provider would provide wireless connectivity at reduced cost in exchange for a full reduction of the rental fee. However, this practice is really just a reallocation of costs.

Summary of fixed-WiMAX vs LR Wi-Fi technologies

Table below draw a comparison between fixed-WiMAX and LR Wi-Fi in terms of the 4 requirements and their sub-criteria :

Requirement	Sub-criteria	LR Wi-Fi	Wimax 16d
Application Requirements	Support for Real time applications and QoS	No support MAC is best effort	QoS built in MAC
Wireless Requirements	Supported Topology	Point to point, not scalable	Point to multipoint. Very scalable
	Support for NLOS	No support for NLOS	Suupport for NLOS up to 10Km
	Power Consumption	Depend on Product	Depend on Product
	EIRP	Built in	Built in
	Antenna Gain and beamwidth, and Antena Diversity	Depend on Antenna device	Depend on Antenna device

	SNR		
	Frequency of operation		
	Dynamic Frequency Steering (DFS)		Usually built in
	Transmitted power Control (TPC)		Usually built in
	Achievable Bandwidth in a MAN type of Network	2 Mbps	10s Mbps
Policy Requirements			
	Frequency		
	Interoperability	No	Yes
	Openess	No	Yes
	Certification	No	Yes
CAPEX and OPEX Requirements			
	CAPEX	low	High: More expensive than LR-WI-FI, but as the business case for fixed-WiMax is being made, this is getting lower and lower
	OPEX	low	High as management requires advanced skills

LR Wi-Fi vs fixed-WiMax Comparison

From the above, it is clear that Fixed -WiMAX is the better option for a large MAN such as the Administrative Man of the city of Fes . In general the business case for LR-Wi-Fi is strong in case of very small scale networks (2-3 nodes), such as a bridge network or an uplink/backhaul network.

Optical Fiber networks available for MANs

Recall that the medium (i.e., optical fiber, coax, twisted pair copper etc.) does not make up for a network by itself. Rather it is the combination of the medium and the active devices (which usually implement one of the networking standards such as IEEE, ATM etc.) that make a network. For instance, FDDI has been the first network to be devised specifically for MANs that uses optical fiber as medium delivering 100Mbps. FDDI active devices were later replaced with ATM switching devices in all MANs, while maintaining the same optical wires to yield a whole new type of network (ATM MANs). ATM switches are now being phased out in many MANs in favor of a newer networking technology namely End to End Ethernet switches. This is to say that putting aside the optical transmission mechanisms (usually SONET or SDH, and recently WDM), the underlying fiber network remains largely the same i.e., a synchronous transmission network capable of transporting regular large chunks of information per frame typically a multiple of 54Mbps from one end of the fiber to the other end, while the active switching devices that implement network (that is the access method, the QoS etc) standards keep evolving yielding better and better networks in terms of bandwidth, Quality of Service, overhead etc.

In what follows, we will give a brief description of optical-fiber, the medium. It will be followed by a description of common Optical fiber-based technologies available for MANs.

Optical fiber: the medium

Optical fiber can be bundled as cables and used as a medium for telecommunication and networking. Light propagates through the fiber with little attenuation, which makes it advantageous for long-distance communications. With Wavelength Division Multiplexing (WDM), each fiber can carry many independent channels, each using a different wavelength of light.

For short distance applications, such as creating a network within an office building, fiber-optic cabling can be used to save space in cable ducts. This is because a single fiber can often carry much more data than many electrical cables, such as Cat-5 Ethernet cabling. Fiber is also immune to electrical interference; there is no cross-talk between signals in different cables and no pickup of environmental noise. Both multi-mode and single-mode fibers are used in communications, with multi-mode fiber used mostly for short distances, up to 550 m (600 yards), and single-mode fiber used for longer distance links.

Modern fiber-optic communication systems generally include an optical *transmitter* to convert an electrical signal into an optical signal to send into the optical fiber, a *cable* containing bundles of multiple optical fibers that is routed through underground conduits and buildings, multiple kinds of *amplifiers*, and an *optical receiver* to recover the signal as an electrical signal. The information transmitted is typically digital information e.g. generated by computers, telephone systems, and cable television companies.

The following table summarizes the advantages and disadvantages of fiber optics.

Advantages of Optical Fiber	Disadvantages of Optical Fiber
-----------------------------	--------------------------------

<ul style="list-style-type: none"> • System Performance • Greatly increased bandwidth and capacity • Lower signal attenuation (loss) • Immunity to Electrical Noise • Immune to noise (electromagnetic interference [EMI] and radio-frequency interference [RFI]) • No crosstalk • Lower bit error rates • Signal Security • Difficult to tap • Nonconductive (does not radiate signals) Electrical Isolation • No common ground required • Freedom from short circuit and sparks • Size and Weight • Reduced size and weight cables • Environmental Protection • Resistant to radiation and corrosion • Resistant to temperature variations • Improved ruggedness and flexibility • Less restrictive in harsh environments • Overall System Economy • Low per-channel cost • Lower installation cost 	<ul style="list-style-type: none"> • Fiber optic components are expensive because of the relative newness of the technology • Fiber optic transmitters and receivers are still relatively expensive compared to electrical interfaces • The lack of standardization in the industry • Many industries are more comfortable with the use of electrical systems and are reluctant to switch to fiber optics
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Optical fiber advantages and disadvantages

Industry researchers are eliminating the disadvantages of optical fiber. Standards committees are addressing fiber optic part and test standardization. The CAPEX resulting from installing fiber optic systems is falling because of an increase in the use of fiber optic technology. Optical fiber cables are being delivered to the Home (FTH) in many countries for broadband access from homes. As the

technology matures, the use of fiber optics will increase because of its many advantages over electrical systems.

Optical based Network technologies

Before embarking on giving some of the present technologies that use Optical fiber for MANs, we will briefly describe the standard SONET/SDH which are used at the physical layer to transmit in a synchronous way on the fiber.

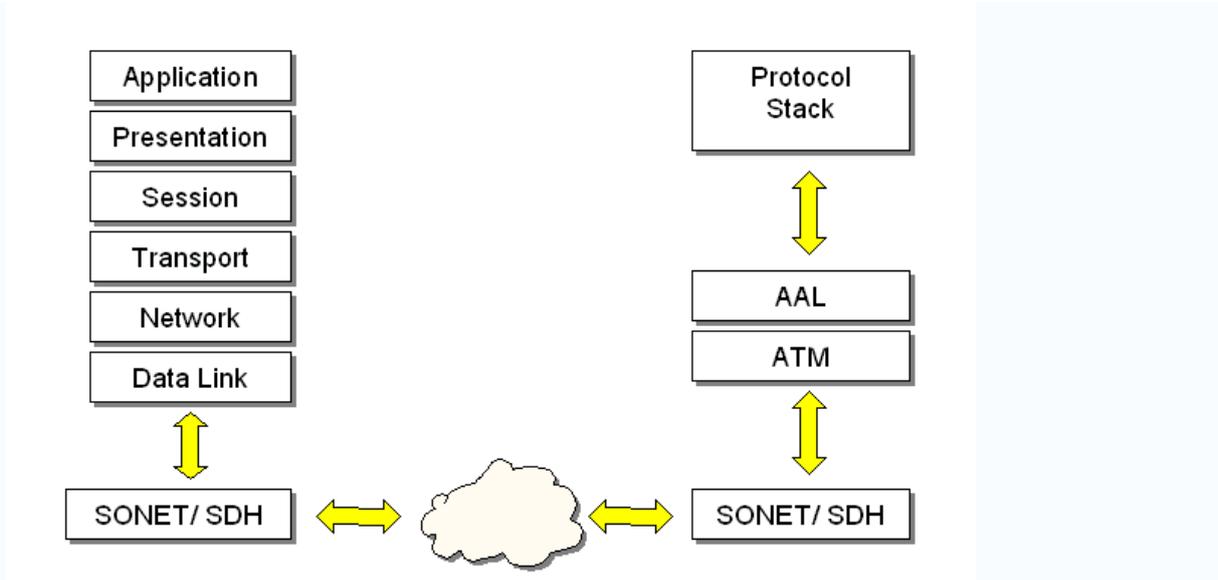
SONET/SDH

Optical based network technologies use SONET/SDH as a transport protocol that transparently manages the optical transmission. In what follows a brief description of SONET/SDH.

Synchronous Optical Networking (SONET) or Synchronous Digital Hierarchy (SDH) are standardized multiplexing protocols that transfer multiple digital bit streams over optical fiber using lasers or light-emitting diodes (LEDs).

SONET and SDH, which is basically the same, were originally designed to transport circuit mode communications (e.g., T1, T3) from a variety of different sources. The primary difficulty in doing this prior to SONET/SDH was that the synchronization sources of these different circuits were different. This meant each circuit was actually operating at a slightly different rate and with different phase. SONET/SDH allowed for the simultaneous transport of many different circuits of differing origin within one single framing protocol. In a sense, then, SONET/SDH is not itself a communications protocol per se, but a transport protocol.

Due to SONET/SDH's essential protocol neutrality and transport-oriented features, SONET/SDH is the preferred choice for transporting many network layer frames such as Asynchronous Transfer Mode (ATM) frames, and Ethernet frames. It quickly evolved to allow the transport of ATM frames, IP packets, or Ethernet in large and concatenated frame (such as STS-3c). As shown in figure below, SONET/ SDH is predominantly a physical layer technology, thus other network functions must be provided by protocol stacks running above the SONET/ SDH layers.



Sonet is a physical layer protocol suite.

Both SDH and SONET are widely used today. SONET in the U.S. and Canada and SDH in the rest of the world. Although the SONET standards were developed before SDH, their relative penetrations in the worldwide market dictate that SONET is considered the variation.

SONET standards describe five types of equipment:

1. Fibre-Optic Transmission System (FOTS). FOTS multiplex STS-1s into STS-ns and also convert electrical STS-s into OC-s.
2. Terminal Multiplexers (TMs). These multiplex T1s to STS-1s (or higher). Both TMs and FOTS are often combined into one unit.
3. Add/ Drop Multiplexers (ADMs). These are placed in series along the route of the FO cable .An ADM is a single-stage device that is used to add or extract individual signals from the FO without having to demultiplex all the signals.
4. Access Multiplexers (AMs). These use the virtual tributary structure and are similar to ADMs but they extract or add individual T1s. The T1s then may be demultiplexed to access individual channels (calls).
5. Digital Cross Connects (DXCs)

Broadband Cross Connect (BBX). These are used in SONET/ SDH to rearrange STS/ STMs within an OC-n.

Wideband Cross Connect (WBX). These are used in SONET to rearrange virtual tributaries (VTs)

Using the above equipment allows for the construction of very flexible WAN and MAN networks. However, for LANs (characterized with short distances) there is no need for these equipment.

WDM

In fiber-optic communications, wavelength-division multiplexing (WDM) is a technology which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths (colours) of laser light to carry different signals. This allows for a multiplication in capacity, in addition to enabling bidirectional communications over one strand of fiber. This is a form of frequency division multiplexing (FDM) but is commonly called wavelength division multiplexing.[1]

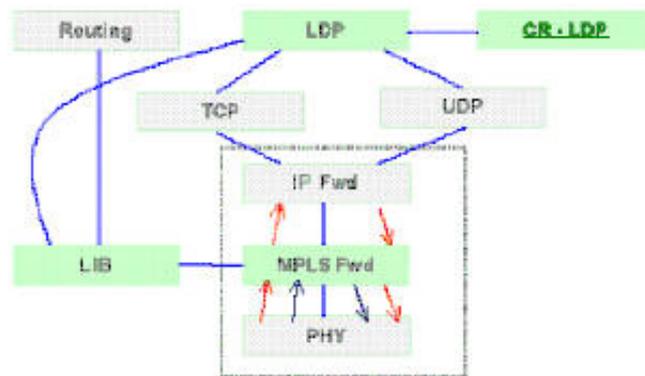
The term wavelength-division multiplexing is commonly applied to an optical carrier (which is typically described by its wavelength), whereas frequency-division multiplexing typically applies to a radio carrier (which is more often described by frequency). However, since wavelength and frequency are inversely proportional, and since radio and light are both forms of electromagnetic radiation, the two terms are equivalent in this context.

Like SONET/SDH, WDM standards also specifies a set of equipment, necessary for building flexible MAN and WAN networks.

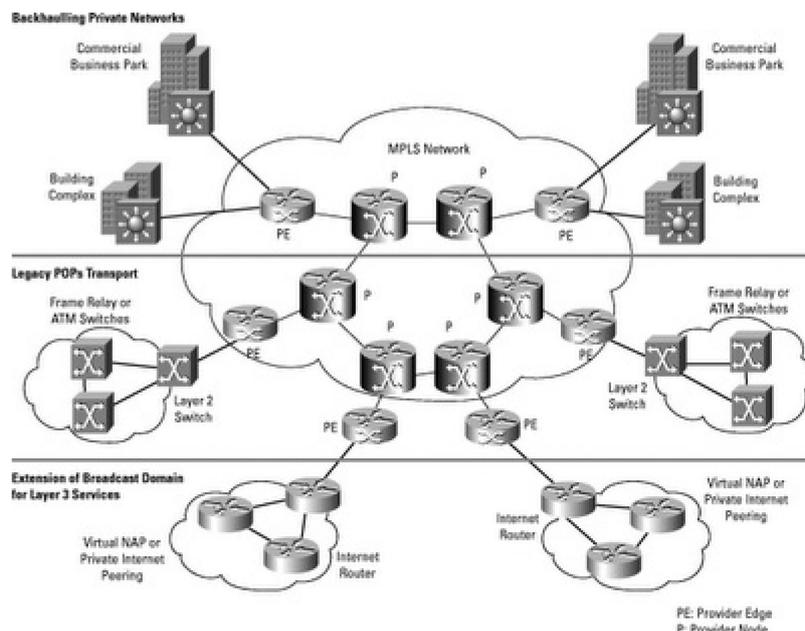
There exist today many optical-based Network technologies adapted to MANs. We will give a brief description of the most prominent ones, namely 10GE and MPLS. In general the architecture comprises 3 layers access network layer a core network layer and a convergence layer.

MPLS

MPLS operates at an OSI Model layer that is generally considered to lie between traditional definitions of Layer 2 (Data Link Layer) and Layer 3 (Network Layer), and thus is often referred to as a "Layer 2.5" protocol. It was designed to provide a unified data-carrying service for both circuit-based clients and packet-switching clients which provide a datagram service model. It can be used to carry many different kinds of traffic, including IP packets, as well as native ATM, SONET, and Ethernet frames.



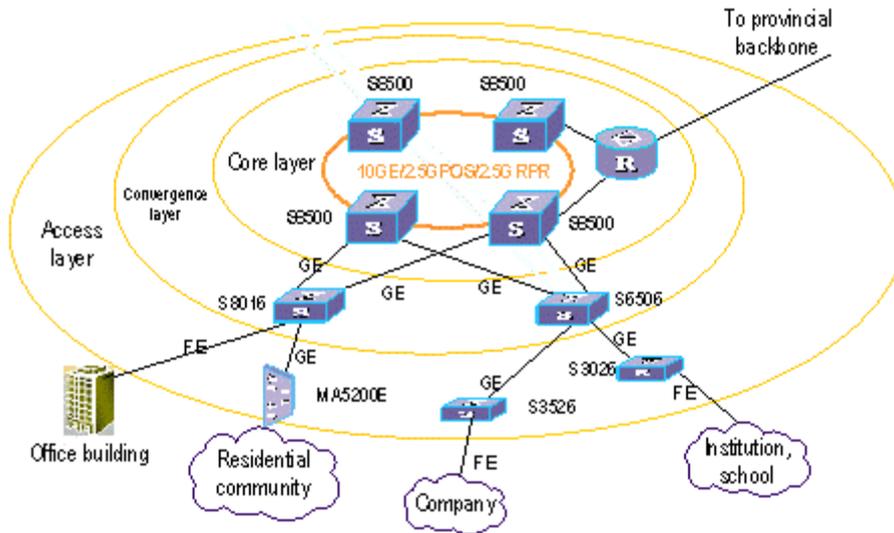
MPLS protocol stack. The PHY can be SONET/SDH optical transmission



Architecture of a MPLS network using SONET/SDH optical transmission

10GE

The 10 Gigabit Ethernet standard encompasses a number of different physical layer (PHY) standards. A careful study is needed to determine which Optical fiber based Physical layer (R, SR, LR, LRM, ER,ZR, LX4) is needed for each link in a MAN. A networking device may support different PHY types by means of pluggable PHY modules.



Architecture of a 10GE network using SONET/SDH optical transmission

Fiber vs. Wireless Access Technologies

This section gives a succinct comparison between Optical fiber and Wireless technologies applicable to MANs. The comparison is drawn along criteria driven by the medium itself, such as bandwidth, Capex, Opex, the build-out strategy (or network extension), scalability, interference, security, and the legal and regulatory issues. The section then gives a summary comparison table between Applicable optical fiber based and wireless based Network technologies for MANs.

Bandwidth

Bandwidth is the most frequently cited distinction between fiber and wireless. Fiber stands above wireless in terms of bandwidth. Theoretically, there is no limit to the bandwidth of a fiber-optic connection, because it allows a dedicated data path between two points, and the bandwidth of that data path is limited only by the capabilities of the equipments at either end. Wireless technology however does not provide a dedicated physical data path; an RF transmitter and multiple receivers are used to turn the air between two points as the data path. This ability to setup point-to-multipoint communication is an advantage that wireless has over fiber, but the bandwidth of a wireless signal is constrained by a number of variables. These include the amount of spectrum (the number of frequencies) authorized to transmit/receive on, the frequency itself (how many cycles per second allowed to transmit/receive), and the modulation scheme (how many bits to push over one cycle). In practice, there is a trade-off between frequency and data-carrying capacity, such that as we lower the frequency (which gives an increased ability to penetrate trees and buildings, a highly desirable characteristic) we lose total bandwidth. But this is not a hard and fast rule, since the other relevant variable here is the modulation scheme implemented in the wireless hardware.

Newer generations of emerging wireless communications standards utilize improved modulation techniques to squeeze more bandwidth out of the same frequency. However the total bandwidths achieved by wireless technologies, especially the ones using the unlicensed spectrum, are still orders of magnitude behind what is possible with fiber. Where most unlicensed wireless setups can deliver bandwidths of multiple megabits per second, the most advanced fiber-optic connections are delivering multiple gigabits per second.

The downstream bandwidth in Mbps, the upstream bandwidth, as well as the Quality of service (QoS) are all important factors for the suitability of a connection for a particular application. Whether or not a fiber-optic connection is suitable for the end-user depends on the layer 2 protocol used (e.g., Ethernet, ATM, SONET...). Ethernet protocol yields “gigabits” transfer rates and it is increasingly deployed over long distances. With wireless technologies, flexibility in upstream/downstream bandwidth is provided, but QoS is more difficult to guarantee if bandwidth is shared between users. As a general rule, better QoS is expected from a fiber-optic connection as it provides a dedicated link between two points.

Installation Costs (CAPEX)

In terms of installation costs, wireless has a decisive advantage over fiber. Fiber incurs costs of preparing a physical path across the terrain between two points, installing the cable itself, and finally, acquiring and installing the data-transmission equipment at either endpoint. Installation of cable entails expenses such as trenching, and pole attachment fees, and is very labor-intensive. This installation is quite more expensive in rural areas where harsh terrain presents obstacles along a direct path between two points. In contrast, the installation costs for wireless are limited to the cost of the base station(s) and Customer Premise Equipment (CPE) devices for end users. In rural areas, no recurring costs are present and deployments of wireless technology across rugged terrain are clear. As

long as the signal can reach its destination without encountering barriers or experiencing attenuation, it doesn't matter what lies in between.

Operation and Maintenance Costs (OPEX)

There are additional cost factors that are recurring beyond the initial installation costs of fiber and wireless. The cost of the dedicated path of fiber between the endpoints frequently carries with it fees, such as pole attachments for aerial construction, and rights-of-way for both aerial and buried construction. If a buried fiber is co-located within another provider's conduit, a fee may be assessed. Wireless can also have some additional recurring costs, such as tower attachment or the rental of space on some tall structure. To offset this cost, some providers have entered into creative partnership agreements with the owner of the tall structure, whereby the provider would provide wireless connectivity at reduced cost in exchange for a full reduction of the rental fee. However, this practice is really just a reallocation of costs.

In terms of maintenance costs, the cost of keeping a fiber connection operational between two points exceeds the cost of maintaining a wireless link between the same two points. Fiber networks are vulnerable to many hazards because they employ physical cables, and once a fault occurs, it must then be located along a cable route potentially spanning several miles. However, with wireless, there is no physical infrastructure to maintain between provider and customer, and faults are by definition at one end or the other.

Build-out Strategies

The nature of build-out strategy or network architecture planning between fiber and wireless is considerably different. With fiber optic architectures, it is immensely important to plan to add connectivity points at all locations envisioned to need service at some point in the future, even if they are not connected initially. This is a limitation of fiber, because it is quite not possible to add a "drop" along a fiber cable at any point along its route. As a general rule, the more access points that are initially built into a network, the less is the amount of additional fiber that will need to be constructed to connect a site that was not initially connected. But the tradeoff here is that each access point increases the overall cost of the initial network deployment. These issues make fiber more readily suited to the backbone layer of the network, where there is a relatively small number of locations that are connected at a very high rate of data transmission.

This limitation does not apply with wireless, because if the number of subscribers in a particular area grows beyond the capacity of a single access point, new ones may need to be added. But this is a less expensive solution than one has with fiber.

The point to take is that with fiber, demand must be demonstrated before construction costs can be justified. In contrast, wireless can be built incrementally in response to or even in advance of demand.

Scalability

There are two relevant dimensions of scalability; scalability in terms of bandwidth (the ability to add more bandwidth in the future), and scalability in terms of architecture (the ability to connect additional sites in the future).

In terms of *bandwidth scalability*, there is not really a big distinction between fiber and wireless. With fiber, the future-proof part is the transmission medium; the glass optical fibers that run between sites. Once a cable is laid, its performance can be increased by upgrading the endpoint equipment. With wireless, on the other hand, the medium is the air itself between the two endpoints, and the

amount of data you can transmit over the air can be increased by upgrading the endpoint equipment. The bandwidth scalability advantages of one technology over the other are going to depend on the relative costs of fiber-optic endpoint electronics vs. wireless transceivers.

In terms of *architecture scalability*, there really is a difference between fiber and wireless. Initial planning as explained above is critical with fiber, whereas wireless networks can be expanded much more easily in the future, as long as careful attention is paid to the load on the base stations and the backhaul connections so as not to degrade the bandwidth quality for the previously existing subscribers.

Interference

With unlicensed wireless technologies spectrum overcrowding can become an issue as the network grows and the number of subscribers and providers increases. This creates *longevity* as well as an *interference* issues. Spectrum overcrowding is not an issue at all with fiber, because a fiber cable forms a closed point-to-point path from provider to end-user, and other signals of the same type do not cause interference. Nor does electromagnetic interference have any effect on fiber, since it uses light waves instead of electrical impulses to transmit data.

Unlicensed technologies, especially those that operate in the 2.4 GHz range are vulnerable to many types of interference; such as interference from a variety of devices (home networks, microwave ovens, and cordless telephones), obstructions caused by the natural terrain and the built environment (many of the higher frequency wireless technologies require a line-of-sight path or near-line-of-sight path), or attenuation (loss of signal strength, but not total obstruction) caused by trees/vegetation.

Security

The central security issue that is a direct consequence of the access technology is the potential for a signal to be intercepted between sender and recipient. With fiber, this is very difficult, if not impossible to do. Since the signal of wireless networks travel through the air, they are inherently vulnerable to threats such as eavesdropping, packet sniffing, and unauthorized connection. This does not necessarily make them insecure, because security should not depend on the transmission medium used at the physical layer of a network, where the access technology resides. Security should be an integral part of networked computing all the way up the protocol stack, and needs to be implemented at the application layer. This means using secure communications protocols (SSH, HTTPS, etc.) that do not transmit sensitive information in clear text. It is true that wireless networks are easier for unauthorized users to access or monitor. But the network should be designed in such a way, and authorized users be trained to secure their communications and data.

Applications supported

With wireless, we are limited to a non-infinite bandwidth and less quality of service than fiber. Wireless connections support almost all types of residential use, and most business applications (web search, e-commerce, e-mail...), however it is not adequate to serve as the primary backbone connection of a region.

On the other hand, fiber connection can be configured to deliver the bandwidth and quality of service to support all known applications of telecommunications. Therefore, anything you can do with wireless, you can do faster with an appropriately provisioned connection over fiber. In addition, fiber can be deployed in all layers of a network including access, distribution, and the backbone itself.

Legal and Regulatory Issues

Both fiber and wireless exist in a legal and regulatory context. For example the question of “who can provide service (i.e., private, public, nonprofit entities)” remains highly contentious for both technologies. With fiber, there are legal/regulatory issues pertaining to rights of way and pole attachments, most of which have to do with the relationship of the provider to a local government. Wireless providers face legal/regulatory questions of unlicensed vs. licensed spectrum, whether or not their technologies create or receive interference, as well as tower attachment and construction ordinances.

Comparison between WiMax and 10GE

Table below draw a comparison between fixed-WiMAX and 10GE in terms of 3 out of the four requirements discussed earlier and their sub-criteria :

Requirement	Sub-criteria	10GE MAN	Wimax 16d
Application Requirements	Support for Real time applications and QoS	QoS is not built in MAC, but ensured by the seizing and poit to point connectkions and the synchronous SONET/SDH	QoS built in MAC
	Broadband (10Mbps per user and beyond)	supported	Not supported
Policy Requirements			
	Interoperability	Yes	Yes
	Openess	Yes	Yes
	Certification	Yes	Yes
	Time to Deploy	Long	short
CAPEX and OPEX Requirements			
	CAPEX	Very high, because of the unavoidable engineering works needed for lying down the fiber	Moderate as the business case for fixed-WiMax is being made, this is getting lower and lower
	OPEX	Moderate. Network management skills are	High as management requires advanced

		available	skills

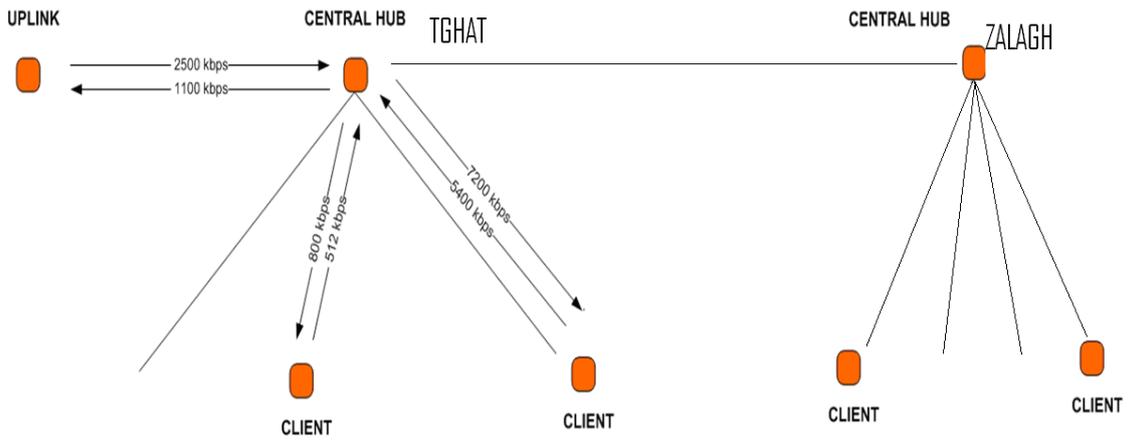
10GE Man vs fixed-WiMax Comparison

From the above, it is clear that Optical fiber based network presents many advantages in terms of broadband, security. It also preserves the investment, as newer and better technologies can always be deployed over the fiber. However, the major disadvantage remains the high CAPEX , which is only justified for a very large MAN, say 100s if not thousands of nodes.

Case Study #1 “Bureaux d’Etat Civil” of the City of Fez

Wman@Fez is a Project that targets the introduction of wireless technologies to Fez local government for various reasons. One underlying motivation is the fact that conducting Fez Wireless Project will complement the ongoing eFez Project which automates public service delivery while using wired technologies. Such technologies enabled the automation of the service delivery conducted inside a BEC office. However, wired technologies were very costly in time and money; and hence, undoable in automating additional critical BEC operations conducted outside the BEC with the Ministry of Justice, specifically the court, and the Ministry of Health especially, obstetrical hospitals . Accordingly, BEC automation was somewhat incomplete because wired technologies were not cost-effective for interconnecting the hospital and court with automated BEC. But, with conducting the wireless ongoing project, it is possible to build a home made wireless innovative extension to eFez project so that to enable the “missing building block” in eFez project: enabling the interconnection between the court and automated BEC in a cost-effective and speedy ways.

Wman@Fez’s vision consists of having the wireless communication infrastructure successfully deployed and functioning. The local capacities are built; and hence, maintaining the wireless infrastructure is being conducted on regular and timely bases. Fez Agdal six BEC offices are using the deployed wireless infrastructure to deliver services to the local community. Thanks to the wireless communication infrastructure, the government offices including the Wilaya office, Fez Agdal BEC offices, ‘Médiathèque’, the court and the selected public park are interconnected for the first time in Morocco’s history. Employees in these government institutions acquired the needed knowledge and skills to better use the new infrastructure. Thanks to the training they received, they use the infrastructure to communicate, interact, and consult each other. Citizens, including women, are very impressed with the concrete noticeable improvements in the service delivery. They are very pleased to see their interactions with their government offices improving in concrete ways thanks to the technology that is being used. Citizens, including women, are very grateful to the deployed Hot Spot allowing them to have free internet access to the government services in the selected public park. Fez local decision makers are very impressed with the positive outcomes of the wireless project at the organizational (employees) and social (citizens) levels. They talk about their wireless experience in their local, national, and international meetings and seminars. The echoes of Fez wireless success attract more and more the media for news coverage. This stimulates interest in other Moroccan cities to have the wireless experience replicated within their respective governance structures. The central government, convinced with Fez wireless demonstration effects and its role model, proceeds in scaling up the experience at the national level.



SITE	Distance [km]	
	TGHAT	
Air Agdal	5.92	
Tribunal	6.76	
BEC Atlas	7.18	
BEC Bouremana	8.31	
BEC Adarissa	7.04	
BEC Dekarrat	4.94	
BEC Agdal	5.81	
BEC Batha	7.01	
Wilaya	6.1	

Max [km] 8.31
Min [km] 4.94

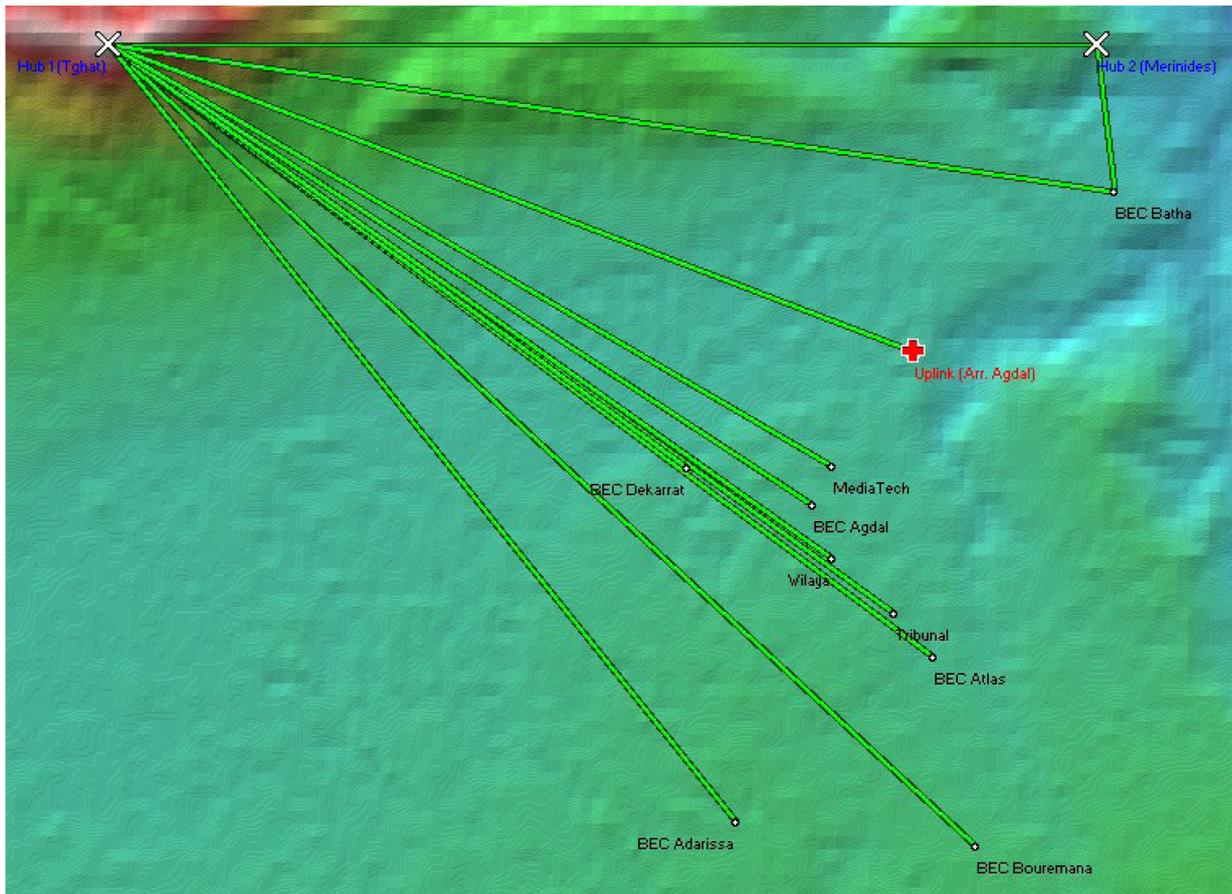


Image 2: Using Tghat as the Central hub will result in average link lengths of 6.5 km and require a sector $H > 42$ degrees.).

As flows is a table of comparison of installation costs of *Optical Fiber*, *WiMax*, and *Microwave Links* technologies based on different cost factors in FEZ city in Morocco.

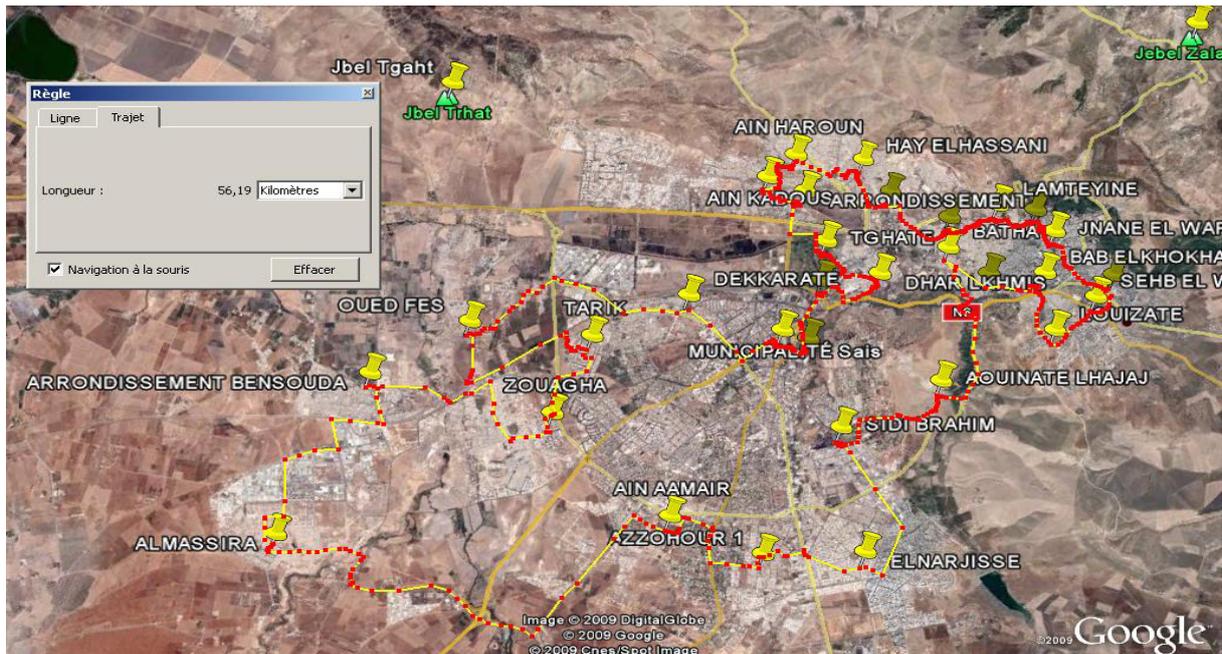


Figure 2. "Bureaux d'Etat Civil" Sites to be connected in the City Fez, Morocco

Figure 1 showcases all the offices and municipalities of Fez city in Morocco, where the study of which technology (fiber optic or wireless access technology) provides better connection and has the best dimensions is made. The broadband access technology will connect all the offices shown in this figure.

	WiMAX		Optical Fiber		Microwave Links	
	Unit Cost	Total Cost (DH)	Unit Cost	Total Cost (DH)	Unit Cost	Total Cost (DH)
Licence	1000 DH/Channel/Year	30.000	30DH/ML /Year * distance	2.100.000	100.000/Year	90.000
Client Equipment Terminal (CPE)	1000 DH/CPE	70.000	2000 DH/Terminal	60.000	-	-
Base Station (BS)	100.000 DH/BS	200.000	-	-	-	-
Integration and Configurations	10000DH/Man Day	70000 DH	10000DH/Man Day	70000 DH	10000DH/Man Day	70000DH

Potelet	40.000	280.000	-	-	40.000	280.000
Pylône	300.000	600.000	-	-	300.000	300.000
Rent /Year	30.000	270.000	-	-	30.000	270.000
Installation Cost	-	-	500 DH/ML	35.000.000	-	-
Link Cost	-	-	-	-	300.000	2.100.000
Total cost in DH	1.520.000,00		37.230.000,00		3.410.000,00	

Table 1. Total implementation cost comparison of WiMAX, Optical Fiber, and Microwave Links

As we can see from table 4, the result of prices comparison among these technologies for FEZ city is as follows: WiMAX has the lowest installation cost (1.520.000 DH) followed by microwave links (3.410.000 DH), and then by Optical Fiber (37.230.000 DH) which has the highest cost among the three technologies.

These costs may be lower in another city in Africa e.g. Sudan, because civil engineering work costs less, and also the technologies' licenses cost much lower.

Case Study #2 Hypothetical sub-Saharan African City

Background

During the World Summit on the Information Society (WSIS), leaders from around the globe, within the spirit of the UN Millennium Development Goals (MDGs), recognized the important role of ICT connectivity in stimulating employment, economic growth and social development and developed a Plan of Action to spread ICT access across all regions. Efforts are underway in all parts of the world to accelerate progress in meeting the goals of the Summit. The Connect Africa Summit is one such effort aimed at mobilizing resources for implementation, especially in initiatives related to infrastructure development [4].

Whilst investment in ICT infrastructure in Africa has improved substantially over recent years, it has been focused mostly on improving mobile infrastructure and access. Significant gaps in backbone networks remain. As a result, the effective high-speed Internet services needed for important key business, government and consumer applications continue to be either very expensive (especially compared to average local incomes) or unavailable (depending on location). Where available, the cost of broadband Internet access in Africa is on average three times higher than in Asia, for example, where significant broadband infrastructure investments have been made. It is not surprising then that broadband penetration is below one per cent in Africa, compared with close to 30 per cent in some high income countries.

These gaps in backbone infrastructure present challenges, but they also represent new opportunities for private investors and innovative “win-win” public-private partnerships to complement the successful experience of mobile telephony in Africa. Recognizing this potential, new players are entering the market. This has increased the need for coordination and information-sharing among public funding partners and the private sector to ensure coherent infrastructure and service roll-out across the region.

City characteristics

A majority of sub-Saharan Africa’s population is not connected to electricity and piped water networks, and even in urban areas coverage is low. Poor coverage of infrastructure services in general.

Conclusion

This comparison has illustrated that “*which is better, fiber or wireless?*” is a wrong question to ask, and that fiber and wireless are complementary technologies that are far from perfect substitutes for one another. Fiber is an essential supporting infrastructure for wireless, and its real strength lies closer to the core of the network than at the edges. Therefore, the legitimate question to ask is “*why not have both fiber and wireless?*” The ultimate goal is to have a ubiquitous, differentiated network where users can choose the delivery technology that best suits their needs.

In the light of the cost comparison in table 4, in which we find data about optical fiber, WiMAX, and microwave links data provided by a company in *Casablanca*, we conclude the following:

- Fiber optic provides high data rate in *Gbps* with good quality link however it is highly expensive compared to other technologies, and susceptible to many accidents as mentioned above. If there is a budget constraint, wireless technologies, especially WiMAX, are suitable for implementing a MAN for cities in Africa like FEZ with lower cost but with a limited data rate of up to 30 *Mbps*.
- Therefore, wireless may serve as a precursor to a more differentiated network, and as demand grows, capacity needs increase, and there is no budget constraint, fiber is there to provide any amount of bandwidth needed now or in the future.

BECs occupy a large number of buildings scattered in various places throughout the city of Fez. Wireless broadband solutions such as fixed-WiMax can for a very moderate cost, efficiently connect the buildings for critical data access, voice services and application sharing resulting in improved internal and public services. Optical-fiber based networks, though, present many advantages remain hindered by the very large CAPEX and the very long deployment time and are typically used and operated by operators rather than organizations. Therefore, there is no business case for Optical fiber based networks outside operators or very rich municipalities which excludes perhaps all African cities.

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