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OWLL: A Future Broadband Alternative for a Least Developed Country

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Abstract. The widespread demand for telecommunication services is creating a need to provide broadband access to business and residential customers in all environments, including those of the developing countries. Optical wireless local loops (OWLL) based on infrared wireless communication links, are class of wireless access networks capable of delivering the type of high-bandwidth services that are becoming increasingly necessary for the aforementioned customers. By combining the use of advanced optical transmission techniques with the flexibility of wireless communication systems, we describe the possibilities that are created by utilizing this technology in the access network. The telecommunications landscape of Tanzania is reviewed and the need for broadband service provision is identified. Moreover, possible implementation options for deploying OWLL systems and a performance analysis of a typical OWLL link are also presented. A comparison with the other wireless-based access technologies is discussed, whereby the competitiveness of the proposed system is further illustrated.

Introduction

Information technology has been the single most significant and defining entity of this current generation, that has been unsurprisingly dubbed the "information age." The operations of transferring, processing, displaying and storing of this information (in audio, visual, alphanumeric or tactile format), collectively known as information technology (IT), comprise the undisputed growth industry of the moment. For example, IT influence on every aspect of human life such as business, education, politics, sports cannot be understated. Consider the following illustrative examples:

- A management team at a mining site in Shinyanga, Tanzania convenes an emergency meeting with major shareholders and company directors, who are actually based in Dar es Salaam, Tanzania at that particular moment.
- Students at the Moshi and Arusha Technical Colleges receive a lecture given by a head of department at the Dar es Salaam Technical College simultaneously.
- An expert surgeon at the KCMC hospital in Moshi, Tanzania supervises and directs, in real-time, a complex heart operation on a patient at the Bugando Medical Center in Mwanza, Tanzania.

These of course are carried out using IT services, namely, videoconferencing[1], tele-education[2] and tele-medicine[3] respectively. The only possible contradiction of these examples is attributed to the fact that none of these services are actually available in Tanzania or any other least developed country (LDC) for that matter. The absence of the proper IT tools and its supporting infrastructure makes it technically challenging and costly to for instance enable the student in Arusha, Tanzania to ask a question as soon

[1] Find out more at http://www.savie.com/.
[2] See http://www.stakes.fi/include/educatio.html.
[3] See http://www.telemedtoday.com/

as the lecture ends in Dar es Salaam. Or for the surgeon in KCMC to receive electrocardiograms and provide instant feedback to the medical team at Bugando. The unfortunate irony of this situation is that, considering the shortage of highly qualified professionals and underdeveloped transportation systems in LDCs, it is obvious that the need for information flow using advanced telecommunication networks is even more urgent than in developed countries. Take the following hypothesis, if Tanzania were a developed country:

⇒ then the shareholders of mining company in Dar es Salaam would be able to get to Shinyanga within a few hours of the meeting being called,

⇒ Or simply, Bugando would have its own team of expert heart surgeons and not resort to "borrowing" one from KCMC.

All these observations suggest that telecommunications should fuel economic development and not the other way round. Indeed, such a conclusion correlates with findings of various studies carried out previously (e.g., Nafstad 1996 or De Greve 1998). The main focus of this paper is the access network or the "last mile" segment of the telecommunications infrastructure (Ims 1998). This is part of the network representing a large chunk of the network operator's investment and also happens to be the immediate point of interface between the operator and the customer. The technologies deployed in the access network usually determine the amount of information that can be delivered to/from a customer in a given time frame.

The access network has traditionally been dominated by legacy equipment based on twisted-pair copper cables. However, fixed wireless access techniques are rapidly emerging as the technology of choice in unbundled (liberalized) access networks and in LDCs, whose penetration of copper cables is extremely low. Unfortunately, the limited capacity of wireless radio frequency (RF) links continues to be a major disadvantage of wireless networks when compared to wire-line access networks. This disparity sees no end in sight, since wire-line networks are now being upgraded to passive optical networks, high-speed digital subscriber lines or cable modems. In this paper we assess the opportunities created by using an optical wireless loop (OWLL) capable of

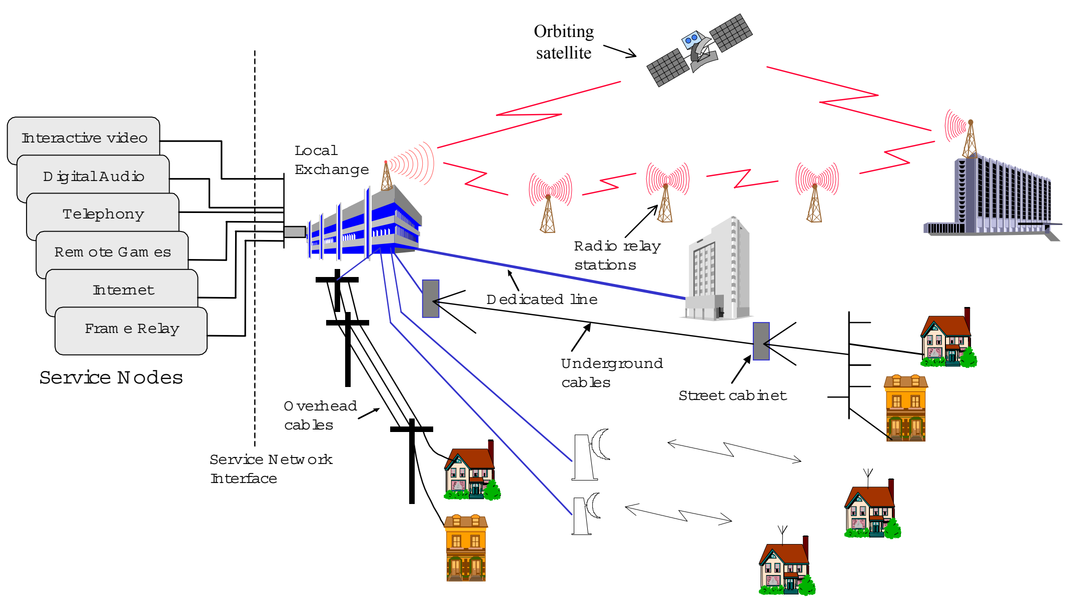

Figure 1. A typical access network architecture.

providing two-way broadband capacity (≥ 2 Mbit/s) in the access whilst retaining most of the advantages provided by wireless techniques. The demand for and merits of deploying an OWLL in an LDC (in this case, Tanzania) are analyzed in detail.

Overview of Telecommunications Service Provision in Tanzania

The deregulation of the telecommunications industry has created a competitive environment in the access network or the "last mile."

Basic Voice Services

The voice communication service is now widely acknowledged as one basic necessity for human survival (Pradhan 1998) with a prioritization almost comparable to food, shelter and clothing. For the three decades following independence in 1961, the state-owned Tanzania Posts & Telecommunications Corporation (TPTC) was sole provider of voice services (also known as plain old telephone service or POTS) in Tanzania via a fixed network[4] (ITU 1988). Within a decade of the publication of the Missing Link Report in 1984, the number of direct exchange lines (DELs) had almost doubled from 44,000 to 85,000 (Kiula 1994). However, the tele-density of 3.1 lines per 1000 inhabitants was still well below the overall African average of 20.1 lines per 1000 inhabitants. These shortcomings encouraged the passing of the Tanzanian Telecommunications Incorporation Act of 1993, which led to the separation of the telecommunications and postal operations, whilst giving birth to the Tanzanian Telecommunications Corporation Ltd. (TTCL) and the Tanzania Communications Commission (TCC). The first fixed network operator to benefit from this liberalized environment was the Zanzibar Telecommunications Ltd. (ZANTEL), which was granted a license in 1996 by TCC to provide local and international voice and data services in Island regions competing directly with TTCL.

Unfortunately, the TTCL monopoly on the provision of fixed voice services in the mainland restrained the tele-density growth throughout the 1990's.

This is in sharp contrast to the development of mobile voice communications recorded within the same period. The number of mobile connections increased by a factor of around 1000 in six years from 500 in 1994 to over 200,000 connections by the end of 2000, easily surpassing the number of fixed DELs. Currently 5 mobile communication licenses have been issued by TCC creating a competitive environment yet be experienced in fixed networks. These operators are MOBITEL with an analog system TACS (operating from 1994) and a digital GSM system at 900 MHz or GSM900 (from 2000), TRITEL (GSM900 from 1996), ZANTEL (GSM900 from 1999) and Vodacom (GSM900 and GSM1800 from 2000). TTCL holds the final license, but has yet to launch its mobile wireless service. Inspired by such rapid developments, TTCL was formally privatized in the first half of 2001 (Nuhu 2001), with a pledge to increase the number of DELs from 162,000 to 800,1000 by the end of 2004.

Narrowband Services

The narrowband services are obtained by accessing the Internet using a connection speed less than 1 Mbit/s. Among them are the well established services such as browsing the World Wide Web and electronic mail (E-mail). Furthermore, a multitude of increasingly popular services are poised to further increase the demand for Internet connections, including Internet telephone communications, Internet banking, chatting and streaming audio. The availability of Internet services in Tanzania can be traced back to the E-mail services offered via FidoNet system in the early 1990's (Ali 1999). Full Internet connections are available through 10 or so Internet Service Providers (ISPs) currently licensed by the TCC[5]. Currently, residential or small business customers use dial-up modems to request an Internet connection from an ISP. The modulation method

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[4] A fixed network has wires (usually copper) running from local telephone exchanges to the customer's premises.

[5] The licensed ISPs are listed at http://www.tcc.go.tz/licences.htm.

commonly used is QAM (a combination of amplitude and phase modulation) and in some cases (for a V.90 modem) pulse amplitude modulation (PAM) is used on the downlink (to customer) (Henderson 1997). Modems operate at various data rates over a voice band telephone channel and these rates are adaptable to the quality of the channel. In practice, the range is anywhere between 9.6 to 45 kbit/s, which is below the 56 kbit/s limit of analog telephone lines. Unfortunately, the telephone lines in Tanzania are poorly maintained, thus subjecting the users to slow click-and-wait Internet connection speeds and increasing the likelihood of connection outage. Integrated service digital networks (ISDN) using end-to-end digital connectivity over regular phone lines could provide a basic rate of 128 kbit/s, but is yet to be deployed in Tanzania due to its considerable digitization requirements. A very promising prepaid Internet service known as Tele2 was inaugurated by Mobitel in June 2001, this service allows customers with dial-up modems to bypass ISPs. The success of such services is not widespread and is usually concentrated in high tele-density regions with locally based ISPs (Dar es Salaam, Arusha, Mwanza and Zanzibar). Internet cafes are currently the only feasible way of providing narrowband services to the wider segment of the population. Unfortunately, the fee charged by the cafes (about US$ 3 per hour) is still beyond the gross disposable income of most individuals[6].

Broadband Services

Broadband Internet connections become necessary when a user needs to browse Webpages containing heavy graphics, stream video, swap detailed images, download CD-quality audio files, and take part in online gaming or share application software. The information content of these broadband services can prove to be too cumbersome for narrow-band connections. For instance, a user with a 33.6 kbit/s or V.34 modem spends at least 16 minutes online to download a single 4-MB compressed music file. A user armed with a basic 2 Mbit/s broadband connection performs the same task in less than 17 seconds. Several options for an operator wishing to provide fixed broadband connections to users that wish to obtain broadband services include:

- *Digital subscriber lines (DSL)*: referred by the generic moniker, *x*DSL, whereby *x* could be A, S, H, and V standing for asymmetric, symmetrical, high speed and very high speed DSL connections respectively. ADSL uses QAM or carrierless amplitude/phase modulation (CAP), Discrete Multitone coding (DMT) and employs 256 different 4 kHz bands in the range 24 kHz to 1 MHz. It is currently the most widely deployed version of DSL and offers data rates between 1.5-8 Mbit/s (Young 1995). The strongest argument for *x*DSL technologies is the fact that it uses legacy twisted copper pairs that have been widely deployed.
- *Cable modems*: an upgrade of cable systems originally intended for broadcast of television signals to support bi-directional broadband communication (Figueroa 2001). Physical infrastructure of the cable TV network is a hybrid of optical fiber and coaxial cables linking the head-end or hub to a cable modem at the customer's premises. The downlink uses a 64 or 256 QAM modulation scheme while for the uplink (from customer) 16 QAM or QPSK modulation. Data rates seen by a user varies between 500 kbit/s and 10 Mbit/s depending on the architecture of the network or traffic load.
- *Fiber in the loop*: laying of fiber cables and optical devices for producing, transporting, routing and receiving light or optical signals in the access network (Ims 1999). Several configurations exist for optical access and are individually referred to as fiber-to-the-*x* (FTT*x*) configuration, with *x* being the point where the optical network unit (ONU, the interface between the optical network and the legacy electronic networks) is located. This could be a house-H, curb-C, street cabinet-Cab, building-B or a radio tower providing an air interface-A. The connection speeds in excess 10 Mbit/s are easily achievable with the conventional intensity-modulated direct-

6 Recent estimates put the Tanzanian per capita income at US$ 240.

detection scheme. Further maturity of optical devices should lower the implementation costs making <1 Gbit/s connections to each customer feasible.

All the broadband access network technologies mentioned above are currently unavailable in Tanzania due to a number of reasons. In order to implement the DSL solution, an almost complete overhaul of the existing but inadequate copper cables a costly proposition undesirable to both the incumbent operator and customers who will be expected to share the cost. The infrastructure for cable networks is nonexistent, effectively ruling out the possibility of using cable networks. Finally, deployment of fiber cable to customer premises is the least feasible option considered here since the cost involved is considered high even in developed countries (Ims 1998). The lack of a fully functional hierarchy of metropolitan, regional and national backbone networks in Tanzania is another factor that makes the deployment of broadband access networks impractical. Furthermore, the only international gateways is via TTCL's Standard A and Standard B earth satellite stations in Dar es Salaam or through the Very Small Aperture Terminals (VSATs) provided by the Public Data Communication Operators licensed by TCC (Luhanga 1995); Ali 1999). The restricted capacity at both the international and national level due to the sub-par connectivity acts as a bottleneck flow of heavy traffic between the potential broadband service providers, content-providers and customers in Tanzania. The existing national Backbone Microwave System (BMS) needs to be upgraded significantly especially the analogue portions of the network.

However, several initiatives are currently underway, with the aim of addressing these shortcomings. The Africa ONE initiative will construct an undersea SDH[7] fiber optic ring around the African continent (Dar es Salaam is one of the 30 landing-points) to carry the inter-African traffic currently routed through Europe (Marra 1996)[8]. A proposal by the public telecommunication companies of the East African Co-operation, has also been made for a 2500 km regional fiber and radio network that will tie in towns such as Bukoba, Mwanza and Dodoma with those in Kenya and Uganda (Mukalazi 1999). Another regional level initiative is the 2500 km fiber link to be laid by a South African-based consortium that will run along the Tanzania-Zambia railway line linking Dar es Salaam to Livingstone (in Zambia), Windhoek (Namibia) and eventually to the international SAT 3 undersea fiber cable in South Africa (Robertson 1999). At a national level, SaskTel International has just completed the digitization of the network in Kagera region and is currently laying an SDH fiber network along the tracks of the rail-lines of the Tanzania Railway Company (SaskTel 2000). Indeed, this is by no means an exhaustive list of the current and future networking initiatives in Tanzania, but it provides a platform for the planning of future broadband access implementations. Wired broadband access networks described here have a long way before they become feasible for the local market. Therefore, the general consensus is that, considering the insufficient amounts of installed wired cable infrastructure, wireless based networks present a more realistic solution for delivery of broadband services in Tanzania and other LDCs (O'Grady 1998). Furthermore, wireless networks present the following advantages compared to wired access networks:

(a). Less up-front investment and maintenance costs (e.g. TTCL customers are usually expected to contribute in buying poles to draw overhead cables to their premises),
(b). They can be deployed in a shorter time (e.g. customer waiting lists in Tanzania usually exceeds 100,000 at any instance in time),
(c). Faults are easier to locate and need less time to repair (could be measured in hours rather than days or weeks),

[7] *Synchronous Digital Hierarchy*- a current transmission and multiplexing standard for high-speed signals.

[8] More recent updates of the project appear at http://www.africaone.com/

(d). Easy scalable to accommodate increase in customer number,
(e). Higher reliability and less vulnerable to vandalism (e.g. copper cables belonging to TTCL are routinely stolen by handicraft people producing bangles etc.).

A wireless access solution proposed by the author is described in Section 3, and in Section 4 comparisons are made with some of the existing wireless alternatives.

Optical Wireless Communication System

In the beginning of the 1990's there was a notable renewal of interest in optical wireless systems due to deregulation of the telecommunication service provision and innovations in portable devices with broadband communication ports (Kahn 1997; Heatley 1998). The establishment of the Infrared Data Association (IrDA) by a group of leading companies and the subsequent standardization activities, is one of the notable outcomes of that interest within the IT industry. The essence of optical wireless system is in the fact that light (operating in the infrared or IR band of the EM spectrum) propagates through air, instead of being guided in optical fiber cables as is the case in optical communications systems (Keiser 1993). This eliminates the costly (and demanding) task of fiber cabling and exploits the absence of optical spectrum licensing requirements. So far most of the work done in this area has focused on the development of infrared indoor communication systems, whereby the coverage is confined within a single room, with the communicating terminals within several meters of each other**.**

There are a range of optical wireless products currently available on the market, for basic tasks suitable for small-office-home-office (SOHO) demands such as the connection of portable computers, copiers, facsimile machines, printers, scanners etc., provision of camera-monitor connectivity in close-circuit TV security applications and infrared wireless enterprise network applications. Significant advances in optical component designs has enhanced the feasibility of outdoor optical wireless links, with results of some field trials indicating error free transmission for distances in excess of 1 km. The most notable of these trials to date managed to achieve an error free transmission of 4 multiplexed 2.5 Gbit/s light signal channels over a 4.4km link (Nykolak 1999). Inspired by these developments, we propose an optical wireless local loop (OWLL), whereby a customer is linked to the exchange by an optical wireless link that is preceded by a "feeder" fiber link. The main elements of an OWLL system are the wireless subscriber unit (WSU) and access network unit (ANU) used to terminate (or originate) a signal at the customer's premises and local exchange, respectively.

Link Designs

Several optical wireless link designs are possible and these can be classified according to their degree of directionality and/or the existence of a line-of-sight (LOS) path (Figure 2). The choice of a particular link design depends on, among other factors, the power budget requirements, link distance, presence of obstacles in the propagation path, demo-graphic patterns, and the type of communication (e.g. point-to-point, point-to-multipoint). Previous power budget analysis and channel capacity evaluations have identified directed or hybrid LOS links as being best suited for outdoor applications (Heatley 1998). The overall power budget of an OWLL link is mainly dependant on the atmospheric-induced path loss incurred along the propagation path. The primary contributions of this path loss are (Kahn 1997):

- *Free space loss* - proportion of transmitted optical power that is incident on the receiver.
- *Air absorption loss* - due to presence of ionic impurities in the air that create a vibration band in the near infrared region.
- *Scattering losses and beam refraction* - attributed to the attenuation caused by water droplets in rainy, misty, snowy or foggy conditions (fortunately some of these conditions are very rare in Tanzania).

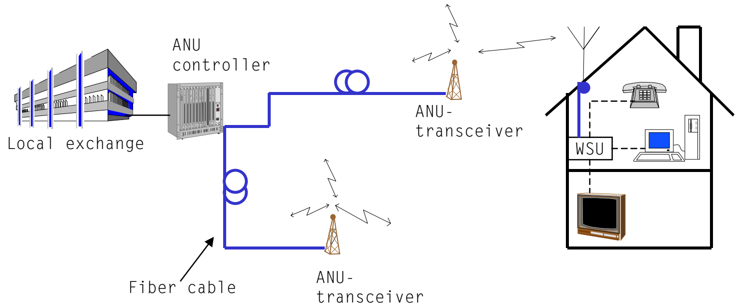

Figure 2. A generic OWLL system

- *Scintillation losses* - this is a form of scattering loss caused by the non-uniform refractive index (due to solar heating) of different pockets of air, this can lead to optical power level fluctuations of up to 30 dB.

Furthermore, the presence of ambient light from external light sources such as fluorescent street lamps or the sun, impair the transmitted signal by introducing photonic interference noise at receivers with a wide field of view (FOV). These stray light signals can be eliminated using plastic infrared filters or employing robust receiver designs.

Modulation/Demodulation and Multiple Access Option

The recommended modulation and/or encoding scheme for low-cost optical wireless systems with a sufficient signal power is on-off keying (OOK) based on intensity modulation[9] (IM). For OWLL applications, vertical-cavity surface-emitting laser diodes (LDs) operating in the Class 3B band are preferred as they offer high electro-optic conversion efficiencies (30-70 %), very narrow spectral widths and multi-gigabit bandwidths (this at least an order of magnitude more than light emitting diodes). To meet eye safety requirements due to the use of high powered LD sources, the communicating equipment are located at rooftop levels or high towers where humans are unlikely to cross the beam. Alternatively, the beam is passed through holograms thus transforming the LD source into a Class 1 eye safe device according to the IEC standard's allowable exposure limits (Heatley 1998). Avalanche photodiodes could ideally provide a high enough SNR when used in DD receivers. But since they have temperature-dependent gain, high costs and operating voltages, PIN diodes are preferred instead. Other modulation techniques that could be considered for future OWLL implementations are listed in (Ghasemlooy 1998).

Since light beams cannot penetrate opaque objects, the efficiency in the IR bandwidth reuse is much higher than what can be achieved with RF wireless systems. Space division multiple access (SDMA) implementation is based on hybrid LOS links using an angle-diversity receiver at the ANU-transceiver to detect signals of the same wavelength band emanating from proximal geographical locations. This offers a relatively better performance (in terms of ambient noise rejection & co-channel interference reduction) compared to a single-element receiver, but at the price of increased cost, bulkiness and complexity. An improved imaging angle-diversity receiver employs an imaging concentrator to signifycantly simplify the receiver structure and support even more receiving elements (Khan 1997). A hexagonal array of LD proceeded by lenses for beam expansion and steering may be used to provide a spatially addressable downlink communications (Fig. 3a). In turn, the WSU need only be equipped with single-element receivers and transmitters; thus minimizing cost & power requirement. The uplink design will be based on a similar spatial addressing technique (Figure 3b) [Street (1997)].

[9] The desired waveform is modulated onto the instantaneous power of the carrier

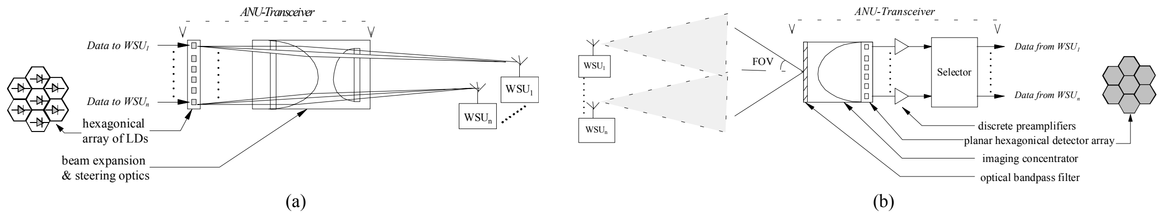

Figure 3. SDMA-based optical wireless local loop (a) downlink and (b) uplink architecture

In the case of wavelength division multiple access (WDMA) each WSU is accessed by a signal of pre-designated wavelength channel. This eliminates the need for transmitter arrays at the ANU, using instead a single non-directed tunable LD to simultaneously produce light at *N* different wavelengths $\{\lambda_i : 1 \leq i \leq N\}$. Single-element tunable receivers are not considered because their input filter designs limit the FOV and are difficult to fabricate. Therefore the ANU multi-wavelength receiver can be implemented using a hemispherical high pass filter and a telescoping non-imaging concentrator to couple light into a multimode fiber (singlemode fibers are too narrow to collect to this beam). The output of the fiber is eventually fed into a wavelength demultiplexer which separates the individual signal channels contained in the aggregate WDM signal and these signals are eventually passed on to a bank of PIN receivers.

Other multiple access schemes also worth considering for OWLL implementations includes time division multiple access (TDMA), code division multiple access (CDMA) and sub-carrier multiple access (SCMA). However, these schemes are yet to be implemented on a large scale even in traditional fiber communications systems.

Performance Analysis of LOS OWLL Link

In this section, we analyze of the performance of LOS links that could be used in SDMA-based OWLL systems. An optical signal would normally be incident on more than one photo-detectors on the detector array. A weighted sum of photocurrents emanating from *N* photo-detectors would then give the received electrical signal. The SNR obtained by this technique is given by (Djahani 2000):

$$SNR = \sum_{i=1}^{N} \frac{\Re^2 P_{RX,i}^2}{\sigma_i^2} \quad \mathbf{(1)}$$

where $\Re$ is the detector responsivity; $P_{RX,i}$ and σ_i are the respective average detected signal and noise power at the i^{th} photodetector.

(a) (b)

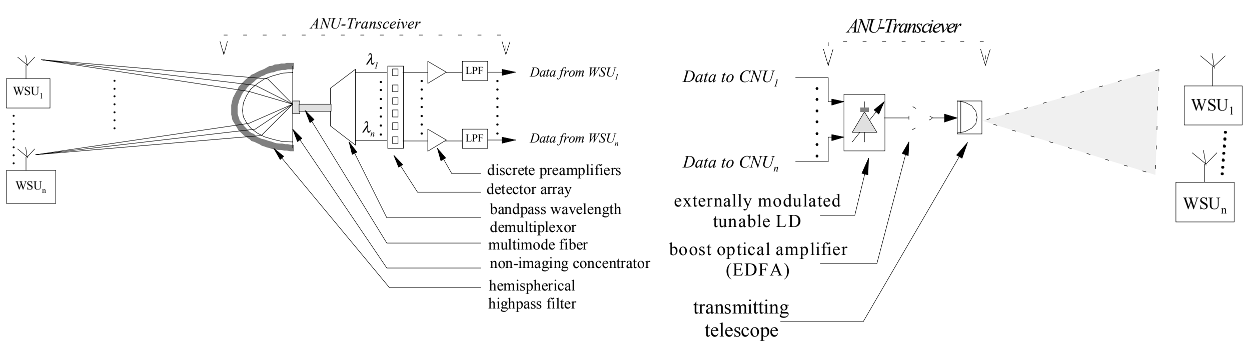

Figure 4. WDMA-based optical wireless local loop (a) uplink and (b) downlink architecture.

Several assumptions are made for further analysis, namely: zero and one bits (0 and 1 respectively) are equally likely to be transmitted, extinction ratio (ratio of power transmitted in 0 bits to 1 bits) is zero and effects of inter-symbol interference (between neighboring bits) can be neglected. The fraction of erroneously transmitted bits (also known as bit error rate or BER) is given by (Keiser 1993):

$$BER = \frac{1}{2}\left[1 - erf\left(\frac{SNR}{2\sqrt{2}}\right)\right], \qquad (2)$$

Where

$$erf(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-y^2}\,dy \qquad (3)$$

For an optical system to be declared virtually "error free" it has to have a BER of less than 10^{-9}. Several methods exist for ensuring the system maintains a low enough BER, however these are beyond the scope of this paper.

The variation BER with the received optical power levels for four different data rates and 100 photo-detectors in the receiver array were analyzed previously (Mutafungwa 1999). The excess losses due to coupling at the transmitter and the receiver mode mismatch have been ignored in this analysis. By increasing the number of photo-detectors, error-free transmission higher bit rates (155 Mbit/s) over a 1.3 km link is possible as long as the area incident beam doesn't exceed the area of a single photo-detector (Mutafungwa 1999). This places an upper bound on the maximum link capacity, which is extendable but at a penalty of increased ambient and thermal noise. Similar analysis could be carried out for WDMA-based OWLL by replacing the parameters for imaging receivers with equivalent parameters for single-element receivers. The effects adjacent channel cross-talk and spontaneous optical amplify-cation noise could be modeled for a more accurate sensitivity estimation.

Competitiveness of OWLL Systems

For OWLL to be competitive they have to offer some significant advantages over the more established radio based fixed access systems (Noerpel 1998). These include:

i. *FWAS*: Based on cordless mobile radio standards (e.g., CT-2, DECT) or proprietary technologies (e.g., Lucent's Airloop, Nortel's Proximity series).
ii. *MDS*: The microwave distribution service could be either the multi-channel multipoint distribution service (a.k.a. the 'wireless cable') or the local multipoint distribution system (LMDS). These systems have proved to be particularly suitable for video broadcasting in areas with rugged terrain.
iii. *CBS*: Cellular-based systems that offer both fixed wireless and mobile services from the widely deployed cellular infrastructure. Originally designed for cellular voice communication and high-tier coverage.

(iv) SATS: The satellite systems that make use of a constellation of low-earth-orbiting (LEO) satellites (e.g. recently launched Iridium system (Fossa 1998), geostationary-earth-orbiting (GEO) satellites (e.g. Astrolink by Lockheed Martin) or hybrid-earth-orbiting (HEO) satellites (e.g. Star Lynx by Hughes).

The overview and description of the cost and performance limiting attributes of the various wireless access technologies are summarized in Table 1. This offers guidance for the comparison of the relative merits and drawbacks of the various technologies and could be crucial for an operator's decision making processes for access network implementations. It is observed from Table 1 that OWLL offers advantages in crucial areas such as data rates, licensing and multipath fading. The issue of cost is one that still works against OWLL.

However, current rapid developments in manufacturing of optical devices should ensure that the cost continues to drop gradually. Moreover, the techniques, such as blowing feeder fibers into cable ducts (Mayhew 1998), will also contribute in reduced investment cost of laying fibers. Several startup companies have been quick to identify the potential for

Table 1. Attributes of various WLL systems (Shading denotes a strong advantage).

Attributes	OWLL	FWAS	MDS	CBS	SATS
Operating frequencies	1-250 THz	3.4-3.6 GHz	28-38GHz,2-3 GHz	800-900MHz, 1.5GHz,2GHz	ka-, ku- & V-bands
Frequency licensing?	None	Yes	Yes	Yes	Yes
Data rate (downlink)	≤ 2.5Gb/s per channel	Up to 128 kb/s, future 25 Mb/s	~100s Mb/s	2Mb/s (UMTS)	Up to 1.5 kb/s
Possible range	≤ 5 km	Up to 35 km	< 8 km	≤ 15 km	Unlimited
Multipath fading?	None	Yes	Yes	Yes	Yes
Relative user equipment costs	High	Lower	Low	Lower	Medium
LOS requirement	Stringent	Relaxed	Stringent	Relaxed	Relaxed
QoS/availability	Weather dependent	Reasonable	Weather dependant	POTS quality	(~99.95%)
Service offerings	Unlimited	Limited	Unlimited	Limited	Limited
Service type	Symmetrical	Asymmetric	Symmetrical	Asymmetric	Asymmetric
Standards	IrDA standards	No agreed standards	No agreed standards	UMTS	No agreed standards

outdoor optical wireless communications, the most notable examples being Optical Access Ltd (http://www.opticalaccess.com/), Cablefree Solutions Ltd. (http://www.cablefree.co.uk/), Airfiber (http://www.airfiber.com/index.htm), Plaintree Systems Inc. (http://www.plaintree.com/investorcontactframe.htm) and Terabeam Corporation (http://www.terabeam.com/hom.html).

Conclusions

In this paper an assessment of the apparent potential of OWLL systems was presented. By combining high information carrying capacity and benefits of wireless systems, this technology offers qualities that are suitable for broadband service provision, especially in an LDC such as Tanzania. Judging from the current traffic growth trends, this solution has high capacity and symmetrical capabilities. Mass production of optical devices and novel fiber cabling techniques has the potential to generate further reductions in investment and maintenance costs of the OWLL systems. This should place this technology in a price-bracket that is affordable for entities such as small- or medium-sized businesses, educational institutes, industrial complexes or government agencies. However, it will take several more years before the technology becomes widely affordable to residential customers in Tanzania. With the telecommunication trends in developed countries migrating rapidly towards broadband optical and 3rd generation mobile networks, OWLL presents a realistic opportunity for provision of broadband services in any LDC.

References

Ali, H. O.: Running Before Crawling: A Tanzanian Internet Story. Proceedings of The Conference of Tanzania: Towards a New Millennium, 1999.

De Greve, M. Osstyn, E.: "Speeding Up the Development of Communities," *Alcatel Telecommunications Review*, Second Quarter, 1998.

Djahani, P., Kahn, J.: Analysis of Infrared Wireless Links Employing Multi-Beam Transmitters and Imaging Diversity Receivers. *IEEE Transactions on Commu-nications*, Vol. 48 No. 12**,** 2000.

Figueroa, J., Guzek, B.: "Cable Modems -Broadband highway to the home," *Ericsson Review*, No. 1, 2001.

Fossa, C., Raines, R., Gunsch, G., Temple, M.: An Overview of the Iridium Low Earth Orbit (LEO) Satellite System. Proceedings of the IEEE Confe-rence on Aerospace & Electronics, 1998.

Ghassemlooy, Z., Hayes, A., Seed, N., Kaluaurachchi, E.: "Digital Pulse Interval Modu-lation for Optical Communica-tions," *IEEE Com-munications Magazine*, Vol. 36 No. 12, 1998.

Heatley, D., Wisely, D., Neild, I, Cochrane, P.: "Optical Wireless: The Story So Far," *IEEE Com-munications Magazine*, Vol. 36 No. 12, 1998.

Henderson P. M.: "56 Kbps Data Transmission Across the PSTN: How Does it Work?." Proceedings of WESCON '97, 1997.

Ims L. (ed.): *Broadband Access Networks*. Chapman & Hall, London, 1998.

ITU.: "Country Profile: Tanzania," Africa Telecom-munications and Information Technology Oppor-tunities Conference, 1998.

JOLT Ltd.: *Long Range High Speed Wireless Link*. Technical Specifications TS-U4000, 1999.

Kahn J., Barry J.: "Wireless Infrared Communi-cations," *Proceedings of IEEE*, Vol. 85, No. 2, 1997.

Keiser, G.: *Optical Fiber Communications*. 2nd edn. McGraw-Hill New York, 1993.

Kiula, N.: "Telecommunications Development in Tanzania," *IEEE Communi-cations Magazine*, Vol. 32 No. 11, 1994.

Luhanga, M.: "Telecommunications in Tanzania," *Virtual Institute of Informa-tion*, 1995.

Marra, W. C., Schesser, J.: "Africa ONE: the Africa Optical Network," *IEEE Communications Maga-zine*, Vol. 34 No. 2, 1996.

Mayhew, A., Mellis, J.: "Blown Fibre as a Reduced Cost Network Planning Solution," *CSELT Tech-nical Report*, Vol. XXVI No. 2, 1998.

Mukalazi, S.: "Plans for Setting Up East African Fibre Optic Link Ready," *The East African*, June 23-30**,** 1999.

Mutafungwa, E., Kazaura, K.: " Assessing Oppor-tunities for Broadband Optical Wireless Local Loops in an Unbundled Access Network", Lecture Notes in Computer Science (Mobile Data Access), Leong, H, Lee, W., Li, B., & Yin, L., Editors, Springer-Verlag, Vol. 1748, Dec. 1999.

Nafstad, H. Iversen, A. W.: "The Role of Information Technology in African Development," *Telek-tronikk*, No. 1, 1996.

Noerpel, A., Lin, Y.: "Wireless Local Loop: Archi-tecture, Technologies and Services," *IEEE Perso-nal Communications Maga-zine*, Vol. 4, No. 3, 1998.

Nuhu, A.: "Teleccommunications Company Privati-sed," *Panafrican News Agency*, March 5**,** 2001.

Nykolak, G., Szajowski, P.F., Jacques, J., Presby, H.M., Abate, J. A., Tourgee, G. E., Auborn, J.J.: "4×2.5 Gbit/s WDM Free-Space Optical Link at 1550 nm." Technical Digest of OFC'99 Confe-rence, Post-deadline Paper, 1999.

O'Grady, V.: "We Want Wireless," *Mobile Comm-unications International*, May 1998.

Pradhan, B.: "Telecommunications: at Least a Phone in Every Village," *IEEE Spectrum*, Vol. 31 No. 3, 1994.

Robertson, D.: "Adding Some Optic Fibre to African Renaissance," *Business Times (South Africa)*, October 10**,** 1999.

SaskTel Ltd.: *SaskTel 2000 Annual Report*. Available online at http://www.sasktel.com/2000_annualreport/pdf/sasktelar2000_complete.pdf.

Street, A., Samaras, K., O'Brien D., Edwards, D.: High Speed Wireless IR-LANs Using Spatial Addressing. Proceedings of IEEE International Symposium of Personal Indoor and Mobile Radio Communi-cations (PIMRC '97), Vol. 3, 1997.

Webb, W.: *Introduction to Wireless Local Loops*. Artech-House, Boston 1998.

Wong, K. K., O'Farrell, T., Kiatweerasakul, M.: "Infrared Wireless Communications Using Spread Spectrum Techniques," *IEE Proceedings on Optoelectronics*, Vol. 147 No. 4, 2000.

Young, G., Foster, K. T., Cook, J. W.: "Broadband Multimedia Delivery Over Copper," *BT Technology Journal*, Vol. 13 No. 4, 1995.