Metropolitan Area Networks using Optical Wireless

Introduction

In this paper we shall look at deployment of Metropolitan Area Networks using Optical Wireless technology in Point-to-Point and Virtual-Point-to-Multipoint™ configurations. Comparisons with Point-to-Point microwave, LMDS, xDSL and Optical Fibre are made.

Metropolitan Area Networks may be deployed by a number of different organisation types. Examples are Competitive Local Exchange Carriers (CLECs), Internet Service Providers (ISPs), 3G/UMTS Cellular Operators, LMDS operators, and private networks for organisations such as large corporates, universities, schools and banks.

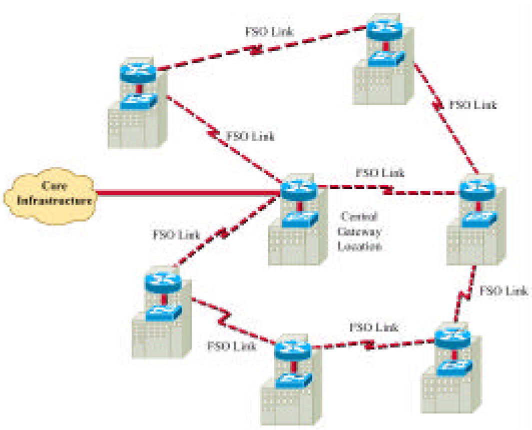
Use of Optical Wireless technology in deployment of Metropolitan Area Networks yields the following benefits:

- High data rates up to 1.5Gbps today
- No need for digging, microwave licenses, frequency planning or land-right issues
- No need for expensive LMDS licenses
- All links fully upgradable from 2Mbps to 1.5Gbps
- Rapid deployment and re-deployment
- Low cost of ownership

Traditional technologies for metro networks include fibre optic and microwave interconnect. Whilst these are invaluable for long-range connectivity, Optical Wireless technology is often a better choice for short hops in dense urban areas.

CableFree's Virtual-Point-to-Multipoint™

Typically, Optical Wireless systems cannot offer true omnidirectional multipoint over useful metro distances, due to limited power budgets constraining beam widths – however, by using a 'virtual' multipoint, with separate beams between a cell-site and each subscriber, extremely high bandwidths in a license-free band can be delivered. Using CableFree's current technology, non-shared full-duplex connections up to 1.5Gbps to each subscriber are available.



Licensing

Optical Wireless systems use the infrared portion of the electro-magnetic spectrum, which is not subject to frequency licensing. By contrast, both Point-to-Point microwave systems and LMDS typically require licenses per-link or per-region respectively.

In all of these cases, service providers offering leased bandwidth are generally required to hold a telecommunication network operator's license.

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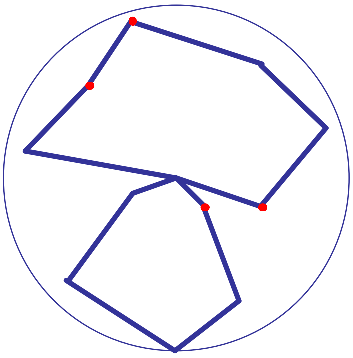
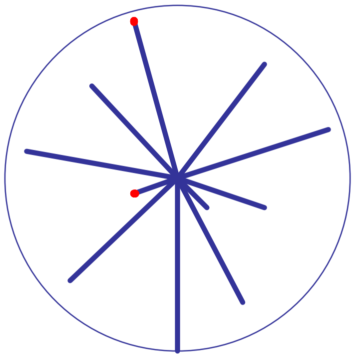
Architecture of Metro Networks using Virtual-Point-to-Multipoint™

Ring



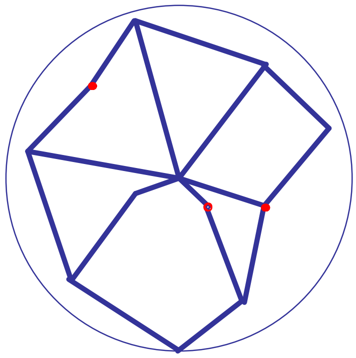
Moderate Resilience
Lowest bandwidth per user
Implement as Sonet Ring with ADM
or Gigabit Ethernet routed IP

Star



Low Resilience
Highest bandwidth per user
Protocol independence
1+1 links improves resilience

Mesh



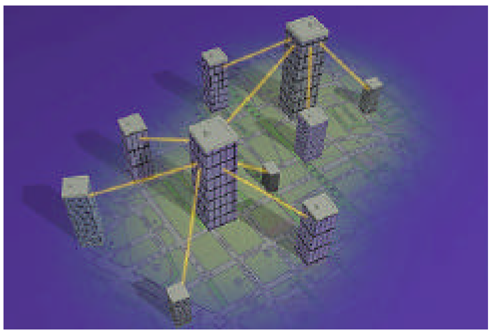
Highest Resilience
Ethernet or ATM design
Routed implementation offers
bandwidth management

Choice of network topology radically affects the performance, reliability, design rules and cost of the overall implementation. Various examples should illustrate this:

- An LMDS-type operator trying to emulate true-multipoint microwave could choose a Star network to provide up to 1.5Gbps capacity to each customer from POP sites
- A CLEC used to deploying Sonet/SDH ring networks might choose a 622Mbs or, alternatively, Gigabit Ethernet Optical Wireless Ring, or to backup existing Fibre rings, or to provide immediate wireless access from a fibre ring to a new customer
- An ISP offering city-wide coverage with over 1Mbps internet connection per user with a high level of resilience would choose an Optical Wireless Mesh network design

Implications of Ring, Star & Mesh architectures

Ring topologies allow customer premises to become ring nodes or, at least, one hop away from the ring. In this way an alternate route is always available in case of link unavailability. At each node, either Sonet Add-drop Multiplexers, or backbone routers are used to interface between data from local users and aggregate ring traffic. The disadvantages are that bandwidth is shared amongst users on a particular ring, and that a common backbone protocol must be imposed.



Star configurations can provide independent connections from POP sites to customers with up to 1.5Gbps non-shared capacity. Traffic latency using a Star topology is the lowest and is predictable. In addition, a suitably configured switch at the POP site can deliver different protocols to each customer. The inherently low resilience of a Star network against line-of-sight blockage or random device failure can be improved by using 1+1 link protection.

Mesh architectures are ones where subscribers are connected simultaneously to two or more base sites, maximising network resilience and flexibility. Routers are used at each node to provide intelligent reconfiguration to avoid network faults. Disadvantages of Mesh are the reduced bandwidth per customer, increased complexity of bandwidth management, and requirement for common protocols throughout the network. Also critical for some applications, latency of traffic will be unpredictable, determined by the number of routers encountered for a given path through the network.

1+1 Protection of critical links

Another technology enabling further resilience is 1+1, where two separate links are deployed between two nodes. CableFree's 1+1 technology can provide so-called 'hitless' switching between links to provide full protection against line-of-sight blockage, equipment and cabling faults. Typically, two transceiver units spatially separated at the POP site are used to connect to the customer premises offering high levels of resilience. [1]

Reliability and Link Availability

The reliability of transmission technologies in Metro Networks can be compared as follows:

- Optical fibre is often seen as the perfect media for transmission, with high bandwidths, and weather-independent performance. However, a fibre break or 'cut' caused inadvertently by other digging activities will cause total outage of the fragile multi-core fibre bundles until a specialised re-splicing repair can be made – taking many hours. In the US, a major fibre break every 10 days on average has been reported in key cities.
- DSL technologies use the copper local loop to provide asymmetric bandwidths up to a few Mbps over traditional telephone lines. Due to age and construction of the copper network, cross-talk between adjacent copper pairs and condition of the wires may result in unpredictable performance. Also, water entering the ducts can cause weather-dependent outages particularly on older copper infrastructure.
- Wireless technologies such as Point-to-Point microwave and LMDS are limited by weather conditions, terrain/clutter morphology and interference. Microwaves suffer during heavy rainfall – the signals are attenuated by water and unavailability increases. This is particularly true in the 'millimetric' bands above 10GHz, which includes the LMDS bands at 24 … 40GHz, and commonly used bands for point-to-point microwave links at 21, 23 and 38GHz.
- Optical wireless systems do not suffer significant rain fade, even in severe tropical rainfall at distances under 2 - 4km. The serious fade mechanisms are thick fog, snow and dust storms, which limit practical distances in Northern Europe to 1 - 2km for reliability. In Mediterranean and tropical climates, where fog and snow are non-existent, this can be increased up to 4km. This is almost an exact opposite to microwaves, for which heavy rain causes outages. Practical deployments of Optical Wireless can achieve per-link availability figures from 99.7 to 99.99% depending on range and geographical region. Deployment of dense Mesh architectures will push overall availability up to the 99.999% expected of resilient telecom infrastructure.[2]

Bandwidth and Scalability

In LMDS deployments, uplink and downlink bandwidth limits exist- based on the frequencies and modulation schemes involved- for a given omnidirectional sectored hub site. The available bandwidth is shared between the subscribers of the respective coverage area. Typically these are asymmetric paths, the upstream data rate being lower than the downstream. As more subscribers are added to the area, a 'saturation' point is reached where either the number of sectors and/or frequencies must be increased, limited by the specific systems in use.

DSL systems are optimised to use maximum capacities available on copper local loop connections. Most commonly, ADSL provides 2Mbps downstream and a lower upstream capacity. These systems can only scale by aggregating several copper DSL connections in parallel. ADSL cannot be deployed in regions with certain cabling types (e.g. aluminium wires) or for subscribers outside a limited cable length from the exchange.

A typical Optical wireless deployment utilises separate point-to-point links between the base site and subscribers, and enjoys symmetric bandwidth limited by only by the technology in use – typically 1.5Gbps in both downstream and upstream directions. The addition of more subscribers does not affect existing ones, as no bandwidth sharing is in use. The ultimate limits are the minimum angular separation of beams (typically 0.1 - 0.5 degrees) and frequencies (or wavelengths), both determined by the type of system in use. In practice, these have not been found to constrain deployment.

Use of Layer-3 router technology within a CableFree Virtual Point-to-Multipoint™ deployment enables scalability, resilience and bandwidth management demanded by large-scale metropolitan area networks. Using bandwidth mechanisms like CAR (Committed access rate), WFQ (Weighted fair queuing) and TOS (Type of service = QoS mapping) all available bandwidth will and can be used.

Security

Multipoint LMDS microwave technologies potentially suffer risk of unintended 'eavesdropping' on data transmitted from the base sites, as the beam widths are large. Conversely, Optical Wireless uses narrow beams (typically 0.1 – 0.5deg), with no side-lobes or antenna-rear-emission – this technology is inherently hard to intercept. For all systems, system security can be increased by the use of DES-grade encryption systems, either software or hardware based.

For end-users in multi-tenant buildings, layer-3 routed design used in CableFree's Virtual Point-to-Multipoint™ architecture gives each user inherently secure VPN connections.

Complementary Deployment of Technologies

LMDS operators, utilising licensed microwave frequencies, can use Optical Wireless to provide additional capacity to customers in congested areas, or to provide resilience in high rainfall areas.

DSL operators can use Optical Wireless to provide higher-capacity connections to customer sites, whilst retaining DSL copper connections as backup or for emergency use.

Metro networks principally employing Optical Fibre can use Optical Wireless to provide permanent or temporary coverage for users in hard-to-reach locations where timescales or cost make fixed infrastructure unfeasible.

Cost models

Metropolitan Networks built using optical fibre suffer from high up-front capital expenditure. For every network element, either backbone or end-customer access, digging is costly and slow in timescale. In practice, limitations on digging permissions in urban areas may determine feasibility of network rollout.

DSL technologies assume existence of a high-quality local-loop cable infrastructure to operate. Costs are modest until customer location requires new cable infrastructure to be laid, which vastly increases costs.

Multipoint wireless technologies such as LMDS deployments tend to incur high capital cost of start-up. The initial implementation costs are in creating transmission hubs and cell sites. Once they are on-line, new costs are incurred only as additional customers are connected. Additionally, LMDS customers requiring high bandwidths up to 155Mbps may cause saturation of available bandwidth for a given sector, requiring significant expenditure in base site hardware to provide more capacity.[3]

By comparison, Optical Wireless deployments have low capital cost of start-up. Apart from base site acquisition and switchgear, the cost of transmission links between the base site and each customer are added only as and when the customers require connection. These costs depend typically on the range and bandwidth required. There is no saturation penalty in cases where many subscribers require high bandwidth connections, as links from the base site to customers are independent, not sharing bandwidth.

Summary

Optical Wireless is a complimentary technology to DSL, Point-to-Point Microwave, ISM-band radio, LMDS microwave and Optical Fibre for broadband multipoint connectivity. The limitations of distance are balanced by the high data rates, license-free operation, low entry-costs, and future-proof scalability of Virtual Point-to-Multipoint™ architecture.

System	ADSL	Optical Fibre	P2P Microwave	ISM or MMDS	LMDS	Optical Wireless
Media / Freq	Copper	Optical Fibre	7-60GHz	2.4-3.6GHz	24-40GHz	30-60THz
Licensed	No	No	Yes	Not at 2.4GHz	Yes	No
Multipoint Topology	n/a	n/a	n/a	Omni or Sectored	Omni or Sectored	Virtual Multipoint
Cell Radius	1-2km	No limit	2-20km	8-15km	2-3km	1-2km
Downstream Bandwidth	2Mbps	10Gbps +	155Mbps	3-8Mbps per sector (per freq)	155Mbps per sector	1.5Gbps per user
Upstream Bandwidth	0.5Mbps	10Gbps +	155Mbps	3Mbps peak per user	3-10Mbps per user	1.5Gbps per user
Symmetric	No	Yes	Yes	No	No	Yes
Protocol Independence	No	Yes	No	No	No	Yes
Fade Mechanism	Water in ducts	Breakage	Rain	Heavy Rain	Rain	Thick Fog, Snow
Initial Cost for few subscribers	Low	High	High	High	High	Low
Cost for 50-100 subscribers/cell	Medium	Medium	Medium	Medium	Medium	Medium

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[1] Note that 1+1 protection for Optical Wireless differs from current market digital microwave radio equipment, where a one- box system is provided. Using Optical Wireless, separate units are deployed with spatial separation to protect against line-of-sight blockage, in addition to equipment failure. Alternatively, Mesh or Ring network topologies can provide equivalent or better protection of service.

[2] Link availability of an Optical Wireless links is notoriously hard to predict in climates where highly localised weather effects such as fog patches exist – typically rural areas. In the majority of dense urban areas, such effects are less pronounced and link availabilities more predictable. CableFree Solutions has extensive experience in site-survey and deployment of mission-critical links in a wide range of climates and diverse geographical regions. In London, UK, availability of individual CableFree 1+0 links in a Service Provider network has been measured at 99.999% even through recent extreme storm conditions.

[3] MAN support for cellular network rollout is particularly attractive for PLMN operators who must apply for scarce microwave spectrum in urban areas. With Optical Wireless, base station time-to-market is drastically reduced. Also, the large throughput of urban loaded LMDS hub sites can only (in most large cities in Europe) be networked using optical fibre and/or Optical Wireless. Optical fibre is not available everywhere; at the same time the Radio Planning process becomes far simpler and much more flexible with Optical Wireless.