Potential and Limits of Photonic systems in relation to Local Area Networks

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Abstract:
We first consider the fundamental physical limits on fiberoptic communication systems and demonstrate that the long term potential is huge indeed. We include a discussion of switching capacity in future electronic systems which also promises to be very large.

Noting that there is strong evidence that although the presently technology driving application is the trunk networks the main costs will be associated with the local area networks and the subscriber terminals we try to identify more fundamental obstacles to realise low cost optical LANs and subscriber terminals with very high capacity.

We discuss some attractive applications requiring such capacities which could motivate the necessary investments

We also try to make a long term comparison between fiberoptic and wireless LANs and their combination.

In many places we try to raise provoking questions rather than providing definite answers.

Which are the fundamental physical limits on fiberoptic communication systems?
In a fiber to the home scenario more than 1 Gbps equivalent circuit switched capacity may well be feasible in the future. The capacity limit of a fiber as determined from Shannons channel capacity theorem by foreseeable available fiber bandwidth (presently about 30 nm) and a power level, about 1 mW, low enough not to cause too much non-linearities is probably at least 100 Tbps.
Accounting for the noise generated in the fiber amplifiers Lars Thylén, Stockholm, has estimated that with present fibers one could ultimately reach about 20 Tbps over long spans and about 40 Tbps over a few km.
Using two polarisations and wavelength multiplexing 160 channels of each 40 Gbps a team from NEC has experimentally reached 6.4 Tbps over 186 km.
On the other hand **single channel electronics and electro-optical converters will probably be limited to considerably less than 1 Tbps**, perhaps to a few hundred Gbps (today about 40 Gbps). However, this will still allow about hundred subscribers using 1 Gbps each to share the same electronic and electro-optical circuit.

Switching
To get some idea of the problem one may, as a thought experiment, consider the total network as one large switch and apply classical switching theory to calculate the necessary number of switch elements, i.e. gates, in different known configurations. Thus with the number of

subscribers $N = 10^9$ one finds that a non-blocking switch of straightforward crossbar type requires about 10^9 gates per subscriber. This may not seem prohibitive but one must remember that the power consumption per gate at 100 Mbps is about 10 $\propto$W with present day technology leading to a power consumption of 10 kW per subscriber. Even if future technology may well reduce the power consumption by a factor of hundred or more such a switching architecture does not seem realistic from e. g. practical topological reasons. Employing well-known architectures for very low blocking probability, e. g. modified Banyan structures, on the other hand, the number of gates required per subscriber is proportional to $\log_2 N$ rather than N. Then both the number of gates and the power consumption per subscriber become insignificant even if the proportionality constant is taken as large as 1000. Thus with $N = 10^9$ the number of gates per subscriber becomes of order 30 000 and the power consumption of order 0.3 W using present day technology. Such a switch architecture seems also well suited to be implemented in a geographically distributed structure.

In conclusion simple estimates indicate that although the presently technology driving application is the trunk networks **the main costs will be associated with the local area networks and the subscriber terminals** where the costs are not shared by a large number of subscribers.
It seems therefore that **very high capacity, self-routing, low cost, virtually non-blocking networks** could be built. They would simply provide fast and reliable point-to-point and multi-point connections and they would not require any operator in the traditional sense. Independent service providers could be connected as subscribers and engaged when needed by other subscribers. Then an interesting question is:

Which are the fundamental obstacles to realize low cost fiber optical LANs and subscriber terminals with very high capacity?
So far we have been able to identify only two. One is the cost for the physical installation of the fiber. Not the costs of the fibers and opto-electronic components themselves that by mass-production can be reduced drastically. Consider the very advanced opto-electronics in standard cheap CD-player! The other, perhaps in a shorter perspective more important obstacle, is that before there is mass-production and low costs there is no big market. This leads to the next question:

Which applications requiring high capacities could motivate the necessary investments to install fiber and to set up mass-production?
There are at least two rather different applications that in time can become important:
- Hi-fi video with resolution and dynamics approaching that of the human eye (requiring about 100 Mbps equivalent circuit switched capacity).
- Rapid downloading huge amount of data for processing in future very high capacity user friendly personal computers with some form of artificial intelligence.

Key factors for the realization of very high capacity LANs may therefore be our ability to develop reasonably cheap and practical very high quality displays and user friendly very high capacity computers with fast large capacity memories. This will probably be possible but it may well require a considerable time.
In the mean time, however, new, as yet unforeseen, applications may of course become apparent.

Long term comparison between fiber optic and wireless LANs and their combination.

Simply because of the much lower carrier frequencies it seems safe to assume that microwave WLANs with truly mobile subscriber terminals can never reach the capacities of a fiber based LAN.
Another well-known difference between a fiber optical network and a cellular microwave network is that the latter due to the use of freely propagating waves is subject to interference problems and requires far reaching regulations concerning frequency allocations.
However, several tens of Mbps should be possible and that would be enough for a lot of new applications.
An operational low cost extremely high capacity fiber optical network would greatly facilitate the technical realization of such a high capacity cellular network. It could provide connections between base stations and to the trunk network. Fiber optical distribution of microwave signals and perhaps even power are also important options.

It should finally be pointed out that **free space, i.e. wireless, optical or microwave links** that can largely overcome the interference problems and in principle have capacities at least of order 10 Gbps will be important options in circumstances where fibers cannot easily be installed.