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# Radio-over-Fiber Techniques for Advanced In-Building Networks

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**Abstract** – With the Optical Frequency Multiplying technique, high-capacity radio-over-multimode fiber networks can be realized for in-building applications. Dynamic wavelength routing provides extra network flexibility for e.g. delivering capacity-on-demand, and can be realized with optical wavelength conversion.

## I. INTRODUCTION

In today's homes, there is a variety of communication networks: coaxial copper cable for video and radio services, twisted pair copper cables for telephony services, cat-5 cables and wireless LAN for IP-based data transfer, infra-red for remote control, etc. A single network integrating all these services would simplify considerably the maintenance and upgrading, and would enable new functionalities by e.g. linking services of different nature. Optical fiber with its huge bandwidth and signal format transparency is an attractive medium for such an integrated network; see Fig. 1. An in-building fiber network can transport both wired and wireless services. Multimode fiber, and in particular large-core polymer optical fiber (POF), is easy to install, and optical transceivers for multimode fiber links are relatively cheap. There also is a large installed-base of silica multimode fiber in office buildings. However, optical power splitting functions are more complex to realize with multimode fiber; hence mostly point-to-point network topologies or point-to-multipoint opaque (i.e. with opto-electronic-optical signal splitters) network topologies are deployed. As an alternative, bend-insensitive single-mode fiber may be considered, which requires more delicate splicing techniques but offers higher bandwidths and optical power splitting devices are more readily available. Hence this fiber type may be better suited for all-optical point-to-multipoint network architectures such as appropriate for large buildings.

## II. RADIO-OVER-MULTIMODE FIBER

Radio-over-fiber (RoF) techniques enable to perform the generation and modulation of all wireless signals in a single place (such as the residential gateway, RG, in Fig. 1), and from there to bring these signals via a fiber network to all the simplified antenna stations (RAP-s, radio access points) in the building. When operating at high radio frequencies (Ultra-WideBand 3-10 GHz, 60 GHz, ...), each RAP covers a pico-cell and can provide a high capacity to the devices within that cell. However, due to its large modal dispersion the

bandwidth of multimode fiber is low, and special techniques are needed to deliver the microwave radio signals. We have introduced the Optical Frequency Multiplying (OFM) technique [1], [2] which is robust against modal dispersion in multimode fiber, and also against chromatic dispersion in single-mode fiber.

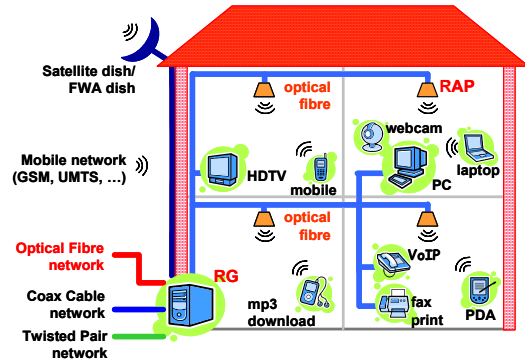


Fig. 1 Integrating wired and wireless services in a single optical fiber network

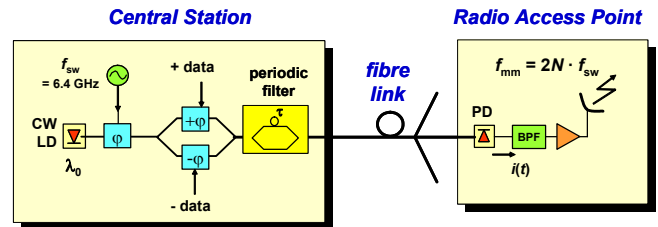


Fig. 2 Optical Frequency Multiplying

The OFM principle (see Fig. 2) is based on periodic sweeping of the optical frequency of a light source, followed by FM-to-IM conversion in an interferometric device (such as a Mach Zehnder Interferometer, or a Fabry-Perot Interferometer). As a result, the output signal after photodetection contains many harmonics of the sweep frequency, of which the amplitudes follow Bessel functions in case of harmonic sweeping. By a simple electrical bandpass filter, the desired harmonic can be selected and emitted as the modulated microwave radio signal. Further analysis [2] shows that a very pure microwave signal can be obtained, as the laser diode phase noise is eliminated in this process. Moreover, the signal withstands dispersion effectively, both the modal dispersion in multimode fiber and the chromatic dispersion in single-mode fiber. We have shown the successful transmission of 16-QAM and 64-QAM

signals up to 120 Mbit/s in the 24-30GHz band over 4.4 km of silica 50 $\mu$ m core diameter graded-index fiber [3]. By using up to 10 subcarriers, we transported 210 Mbit/s 64-QAM over the same link [4]. We also demonstrated a 100Mbit/s 16-QAM bidirectional system at 17.2 GHz over 100 meters of 50 $\mu$ m core graded-index POF [5], where the microwave available at the antenna site is used for down-converting the upstream radio signal. Hence the OFM technique is advantageous for distributing RoF signals in multimode fiber in-building networks.

### III. DYNAMIC RADIO CAPACITY ALLOCATION

When users are moving around in buildings, the traffic loads on the RAP-s may change. By dynamically routing one or more RoF signals from the RG to a RAP, the capacity of the RAP can be adapted in order to meet these changes. As illustrated in Fig. 3, in a point-to-multipoint network architecture optical routing nodes (RN-s) may be deployed to direct the RoF signals to the appropriate RAP-s.

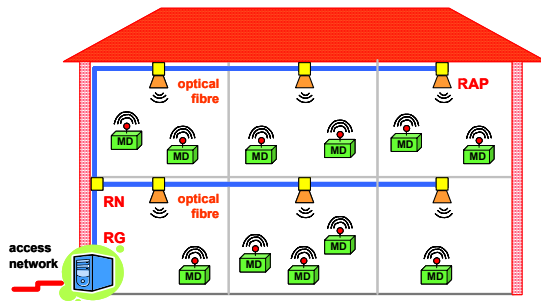


Fig. 3 Routing of radio-over-fiber signals (RN = routing node, MD = mobile device)

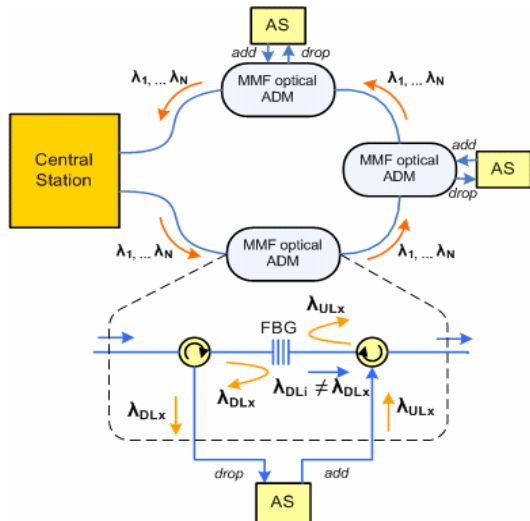


Fig. 4 Wavelength-routed radio-over-multimode fiber network (ADM = add-drop multiplexer, FBG = fiber Bragg grating, MMF = multimode fiber)

Using static FBG-based wavelength add-drop multiplexers, the feasibility of the concept has been demonstrated in a ring network with 50 $\mu$ m core multimode silica graded-index fiber, where three wavelengths (1304, 1310 and 1315nm) each carried a 120Mbit/s 64-QAM RoF signal at 23.7GHz [6].

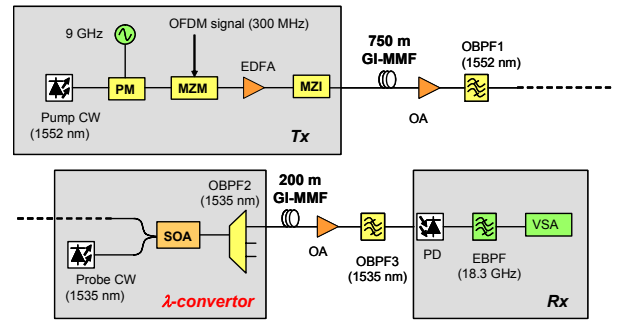


Fig. 5 Wavelength-conversion of OFM RoF signals

To achieve dynamic routing, tunable wavelength conversion may be introduced in the RN. We performed wavelength conversion by cross-gain modulation in a semiconductor optical amplifier (SOA) fed by a local probe laser diode; see Fig. 5 [7]. A static wavelength router after the SOA determines the routing path. The probe laser diode may also be located at the RG, which enables remote all-optical control of the routing. Successful conversion and transport of a 18.3GHz RoF signal carrying 36Mbit/s 16-QAM data on 52 OFDM subcarriers was achieved over 950 meters of silica 50 $\mu$ m core graded-index fiber.

### IV. CONCLUSIONS

The Optical Frequency Multiplying technique is a promising approach for providing high-capacity wireless services over a multimode fiber in-building network. By means of wavelength conversion and optical routing in a point-to-multipoint network architecture, the fiber network can efficiently deliver wireless capacity on demand.

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