MM-Wave and Optical Hybrid Wireless Link Design and Implementation for All Weather and High Availability

Hossein Izadpanah, Tamer ElBatt and Greg Tangonan

HRL Laboratories, LLC - 3011 Malibu Canyon Road, Malibu, CA 90265, USA

Phone: (310) 317-5563, Fax: (310) 317-5485

hipanah@hrl.com, telbatt@wins.hrl.com

Abstract

We introduce an "all weather survivable" optical/mm-wave wireless access and distribution network architecture and examine the merits of various techniques for enhancing the network availability, namely hybrid link protection, dynamic load switching, and multi-hop routing.

1. Introduction

The surging need for broadband communication links to reach individual users in any geographical environment require the integration of network segments consisting of wide variety of transmission media such as metallic wire, fiber, and *RF* or optical wireless. In the meantime, there is an increasing need for high data rate connectivity among high bandwidth users in densely populated metropolitan areas. Providing high-speed access to these users (*last-mile*) is the key challenge towards realizing this objective. Although, fixed wireless connectivity is the an attractive solution to the access segment of the network due to the ease and low cost of installation, classical *RF* system bandwidth is limited and can not fully utilize the high bandwidth offered by the fiber optics backbone. However, Free-Space Optical Wireless (*FSOW*) is an emerging fixed wireless access technology that can be used as an alternative to *RF*-based platforms and is capable of supporting extremely high bandwidth wireless access and distribution networks. This technology, in combination with the well-established *mm-wave* technology, has effectively increased the achievable data capacity of wireless channels and hence made it possible to extend the full potential of ultra high-speed fiber backbone networks to the access and metro area distribution networks.

In this paper, we introduce novel high availability hybrid network architecture and present interface technology solutions for a protective networks consisting of *RF*, *mm-wave*, and *FSOW* access and distribution sub-networks. The following techniques were examined and shown for traffic distribution to be effective in enhancing the *FSOW* link availability: (1) Power control, (2) Providing *hybrid link protection* [1,3,4] via *RF* (microwave/mm-wave) switched links, and (1,3) scaling down the distance between transmitter-receiver pairs via multi-hop routing [1,4]. In this paper, we review both technologies and introduce necessary networking algorithms. To this end, we first define the notion of "*Instantaneous Link Availability"* that accurately reflects the dynamic link status under various weather conditions. We introduce a simple, yet efficient, algorithm for dynamically detecting link availability based on measured bit error rate (*BER*) data. Afterwards, we investigate the aforementioned two approaches for availability enhancement. Measured and simulation results show the large performance gains achieved by the hybrid protective link approach. This, in turn, emphasizes the important and effective role dynamic load switching (*DLS*) schemes we utilize in maintaining all-weather link connectivity, availability and efficient utilization of the links' capacity.

2. Hybrid (1:1) Link Protection

An "all-wireless" hybrid network architec-ture [1-4] is adopted to extend the fiber optics backbone reach and to enhance the wireless network availability. The side-by-side *FSOW/mm-wave* hybrid network shown in Fig. 1 has facilitated direct performance comparison between the *mm-wave* and *FSOW* links in various environmental conditions (*e.g.,* multi-path, rain and fog fades).

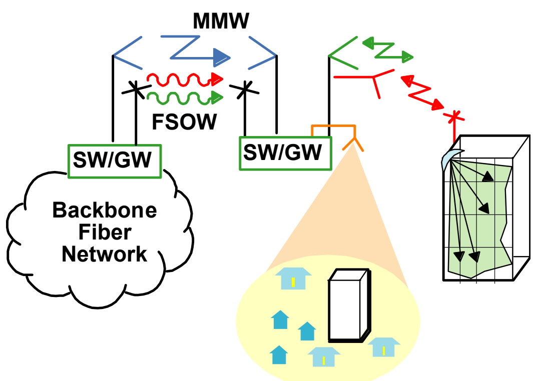

Fig. 1. All wireless hybrid FSOW/MMW links.

It is well known that the performance of *RF* systems severely degrades under heavy rain conditions, especially at frequencies above 10 GHz. On the other hand, while *FSOW* links are relatively less sensitive to rain, they are adversely affected by steam, mist or dense fog. However, using the hybrid solution, it is possible to achieve un-interrupted network access even during adverse weather conditions. A typical FSOW/mm-wave measured BER is shown in Fig. 2.

During a relatively heavy fog period, the FSOW link undergoes a high error period

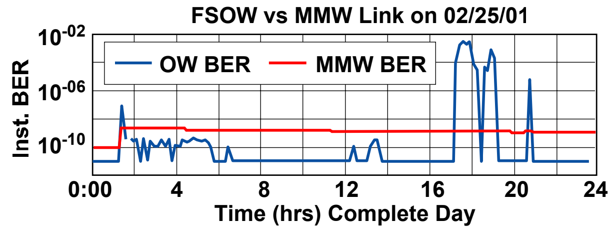

Fig. 2. Hybrid link measure BER

while the mm-wave link is unaffected. To use this complementary availability hybrid link feature, here, we propose and implement a *DLS* algorithm that partitions the traffic load, over a point-to-point link, between the two types of links depending on weather conditions, desired link quality, and transmission delay constraints.

3. FSOW Link Availability

Our objective in this section is to provide a methodology for characterizing the dynamic status of optical wireless links. This algorithm should satisfy the following constraints:

- Filters out frequent link state alternations due to temporary line-of-site obstructions.
- Avoids unnecessary activation of the expensive *DLS* algorithm.
- Preserves accurate characterization of long stable periods of link availability/outage.

Accordingly, we introduce smoothing the measured *BER* data via a *Sliding Window* averaging mechanism in order to filter out temporary, sudden changes as shown in Fig. 3.

Two parameters need to be specified for this algorithm, namely the *window shape* and the *window length* (*W*). In this study, we employ a rectangular window where all samples are given equal weight in the averaging operation. Investigating the impact

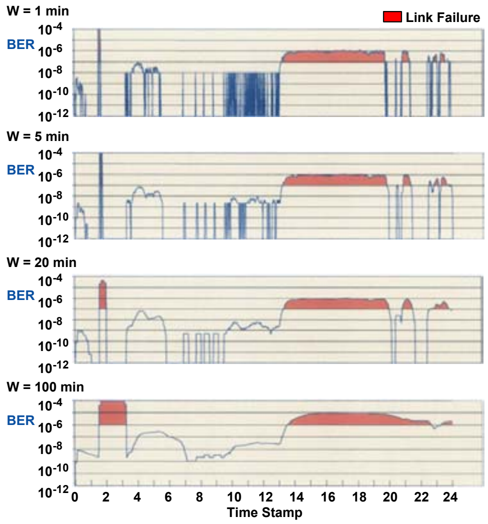

Fig. 3. Window size dependent link availability

of window shape on availability is out of the scope of this paper and is a subject of future research. On the other hand, we examine a wide range of window lengths varying from *W = 1 min.* to *100 min.* The link availability/outage state, in each scenario, is defined according to an acceptable pre-specified bit error rates. Fig. 4 shows a typical one and ten minute window length recorded BER for FSOW link showing different availability characteristics.

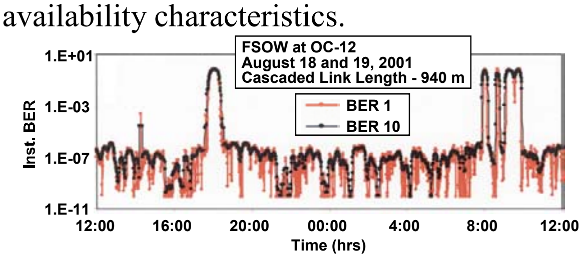

Fig. 4. Measured BER for two window sizes.

4. Dynamic Load Switching

In this section we present a novel algorithm for efficiently utilizing "*All-weather*" hybrid *RF/FSOW* wireless links. Fig. 4 shows the measured *BER* over both links and, hence, emphasizes the complementary weather sensitivity characteristic of hybrid links.

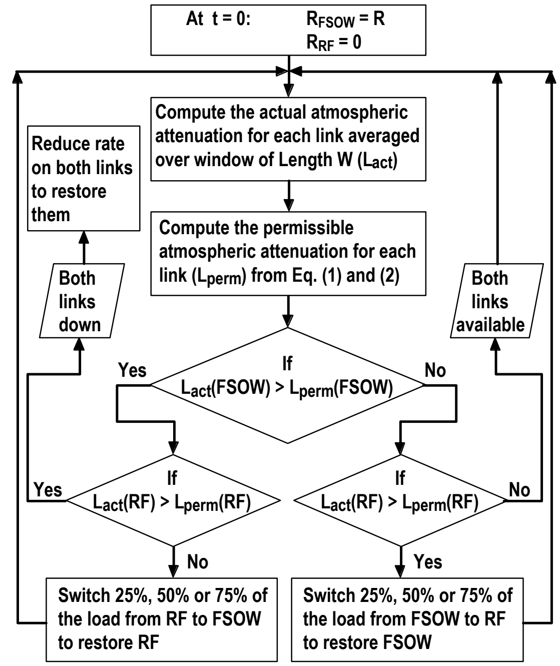

Fig. 5. Window averaging algorithm and flowchart.

Figure 5 illustrates the operation of the proposed algorithm. In this study we consider the *FSOW* as the main operating link and the *RF* link(s) as a backup that should takeover part of the load whenever necessary.

Throughout the simulations, we assume that initially the whole traffic load is transmitted over the *FSOW* link and the *RF* bit rate $R_{RF}=0$. The *DLS* increment size is $R/4$ where R is the maximum bit rate supported by the *FSOW* link. The decision step compares the actual atmospheric attenuation to the permissible atmospheric attenuation for each link in order to identify their dynamic status according to one of the following four cases: (1) Both links are available, (2) *FSOW* down and *RF* available, (3) *RF* down and *FSOW* available and (4) Both links are down (*e.g, rainy foggy weather conditions*). The *DLS* algorithm switches load between the two links depending on their dynamic status. Figure 6 shows a typical dynamic behavior of the actual and permissible atmospheric attenuation of the *FSOW* link over measure BER time.

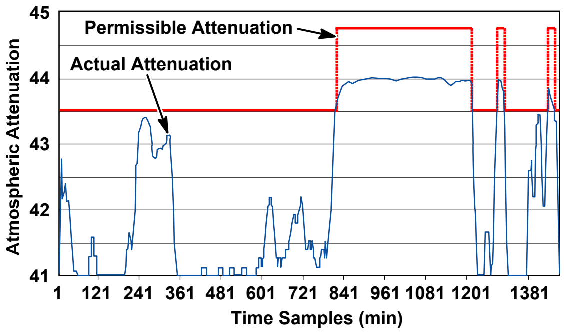

Fig. 6. Window averaging (a), measured hybrid link BER (b), and DSL link performance (c).

5. Multi-Hop Routing

In this section we discuss improving link and network *availability* via multi-hop routing. The rationale behind this approach is that going from source to destination over a multi-hop path consisting of short-length links as shown in Fig. 7, would achieve higher availability than going over a long single-hop. On the other hand, sending packets over large number of hops would increase the end-to-end delay, which, in turn, leads to QoS degradation for *real-time* applications. Thus, there is a *fundamental trade-off* between path availability and path delay. Shortest-path (*SP*) routing relays packets through the shortest path, where the link metric could be *physical length*, *transmission delay* or *load* depending on the QoS parameter of interest.

For optical wireless networks, we believe that the link's atmospheric attenuation should affect the routing decision. As described in the previous section, speed of optical wireless links can be traded for their availability, *i.e.,* the bit rate of an *FSOW* can be reduced in order to increase the permissible atmospheric attenuation and hence improve its availability. Accordingly, the network would consist of a number of *heterogeneous* links ranging from *high-speed low-availability* links to *low-speed high-availability* links. The objective is to route packets efficiently in this "*heterogeneous*" network environment according to

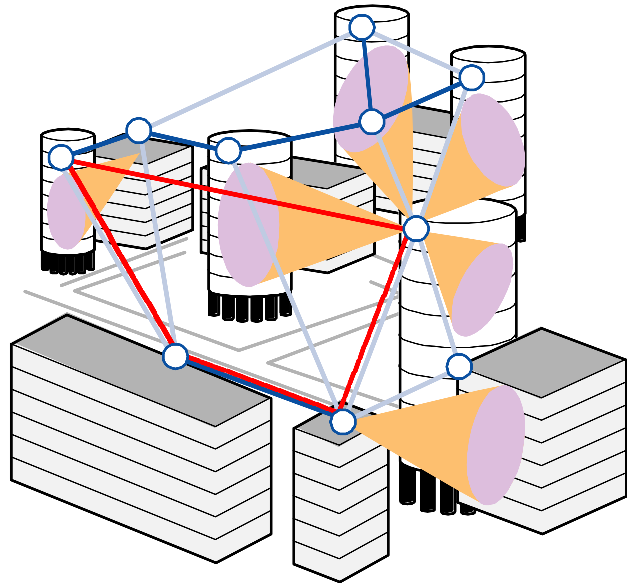

Fig. 7. Availability multi-hop routing scenarios

the their QoS requirements. Introducing specific routing algorithms for *FSOW* networks is a subject of ongoing research.

In conclusion, we presented several system architecture and design trade-offs for a hybrid *mm-wave/FSOW* system. Furthermore, we introduced a novel dynamic load-switching algorithm for high link availability figures and efficient utilization of hybrid link capacity.

6. References

1. *Izadpanah, H., "Access Network Technology For All Wireless WDM Communication system", ITCom2001, August 2001, Denver, Colorado*.
2. *ElBatt, T. and Izadpanah, H. "Design Aspects of Hybrid/Free Space Optical Wireless Networks", IEEE Emerging Technology Conference, Rich*ardson, TX, Sep. 10-11, 2001.
3. *Clark, G., et al., Proceedings of SPIE, vol. 4214, 2001.*
4. *Dodley, J.P. et al., Proc. of SPIE, vol. 4214, 2001*.