An Integrated Availability Analysis of RoF Networks

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ABSTRACT

The emerging vehicular applications such as active safety, infotainment, interactive games, and wireless Internet access might dictate very high reliability and availability in future radio over fiber networks. This paper provides an integrated analysis of availability of the optical fiber network and the wireless network, in future radio over fiber systems. We present an integrated comparative analysis of network topologies for radio over fiber networks. In particular, we present results that compare different topologies such as multilevel rings and hybrid multilevel ring-stars in terms of availability. Protection schemes are also considered and results on the protected versions of the aforementioned topologies are also presented.

1. INTRODUCTION

Increasing interest in road accident prevention, radar vehicular technology, and traffic congestion in intelligent transportation systems has triggered research activities in the information and communication technology sector to develop secure and reliable network infrastructure for such applications [1]-[11]. As shown in Figure 1, fiber network topologies investigated in this paper can be used for Radio over Fiber (RoF) services as well as for fiber to the home and fiber to the building services. Due to the vast bandwidth of the fiber, both wireless and wired services in a single fiber access network can co-exist. However, this will require network planning to distribute the bandwidth for both services according to the traffic and demand requirements. Without proper security and availability mechanisms, networks will be confined to limited, controlled environments, not fulfilling much of the promise they hold. The limited ability of Vehicular/Mobile/Wireless/Computer networks to thwart failures or attacks makes ensuring network availability more important and difficult. Consideration of security, reliability, and availability at the design stage is the best way to ensure successful network deployment [1]. This communication system has great potential to support secure, cost-effective, and high capacity vehicular/mobile/wireless access. For the future provisioning of broadband, interactive and multimedia services over wireless media, current trends in cellular networks are: 1) reduction of the cell size to accommodate more users; and 2) to operate in the microwave/millimeter wave (mm-wave 30 – 300 GHz) frequency bands to avoid spectral congestion in lower frequency bands (2.4 or 5 GHz). The larger radio frequency (RF) propagation losses at mm-wave bands reduce the cell size covered by a single base station (BS) and allow an increased frequency reuse factor to improve the spectrum utilization efficiency [6]. On the other hand, this type of network demands a large number of BSs to cover a service area, and cost-effective BSs are key to success in the market place. This requirement has led to the development of system architectures where functions such as signal routing/processing, handover and frequency allocation are carried out at a central control station (CS), rather than at the BS. Furthermore, such a centralized configuration allows sensitive equipment to be located in a safer environment and enables the cost of expensive components to be shared among several BSs. An attractive alternative for linking a CS with several BSs in such a radio network is via an optical fiber network. The transmission of radio signals over fiber, with simple optical-to-electrical conversion, followed by radiation at remote antennas, which are connected to a central CS, has been proposed as a method for minimizing costs [1]-[11]. This cost reduction can be brought about due to the following three advantages. First, the remote antenna BS or radio distribution point needs to perform only simple functions, and it is small in size and low in cost. Second, these simple antennas can be installed on the traffic lights or on electric poles avoiding the expensive right of way costs of private owners of buildings where today's antennas need to be installed. Third, the resources provided by the CS can be shared among many antenna BSs.

The distribution of radio signals to and from BSs can be either mm-wave modulated optical signals (RF-over-fiber) [8], [9] or lower intermedium frequency subcarriers (IF-over-fiber) [10], [11] as shown in Figure 2. When signals are modulated at an intermedium frequency the dispersion compensators can be avoided, however an intermedium to radio frequency transceiver is required to up convert and down convert signals as shown in the figure. These research activities, fueled by rapid developments in both photonic and mm-wave technologies suggesting simple BSs based on Radio over Fiber (RoF) technologies, will be available in the near future [2]. This paper provides an integrated analysis of availability of the fiber network and the wireless network, in future Radio over Fiber systems. We present a comparative analysis of network topologies for radio over fiber networks. In particular, we present results that compare topologies such as multilevel rings and hybrid multilevel ring-stars in terms of availability. Also, we analyze the wireless network part and present fiber and wireless network availability results. Protection schemes are also considered and results on the protected versions of the aforementioned topologies are also presented.

The remainder of the paper is organized as follows. Section 2 presents the considered network topologies. Section 3 outlines the methodology used for availability calculations and present results of the fiber network and wireless network. Conclusions are presented in Section 4.

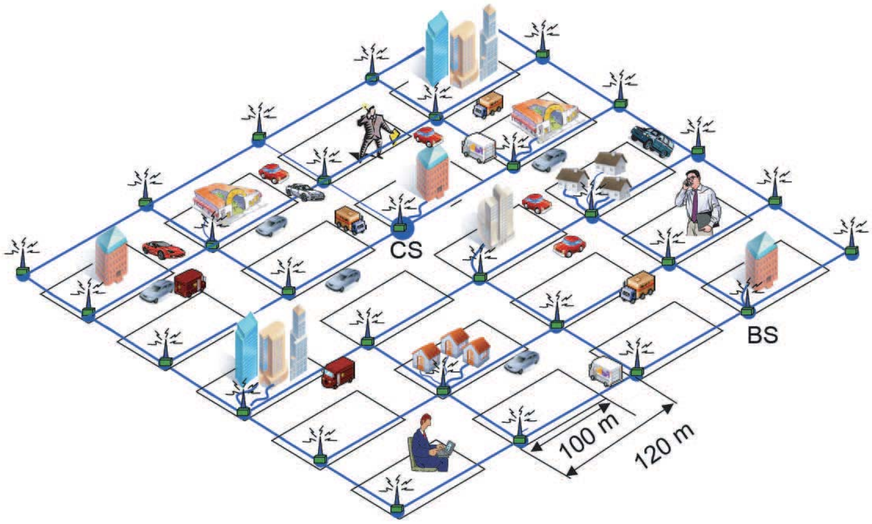


Figure 1. The envisioned radio over fiber network in urban areas. Radio over fiber for vehicular, mobile, broadband wireless computer communications and also network infrastructure can be used for fiber to the building and fiber to the home services.

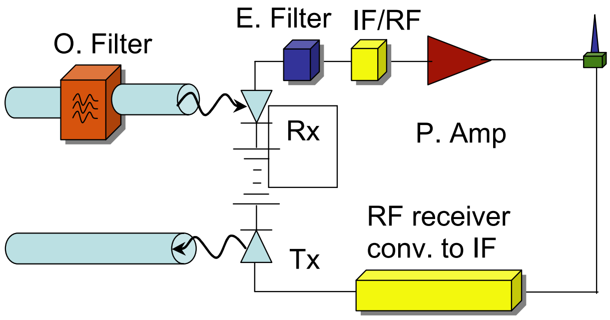


Figure 2. Architecture of the wireless BS system.

2. NETWORK TOPOLOGIES

Figure 3 shows topologies with 25 nodes where Fig. 3*a* is a multilevel rings and Fig. 3*b* is a multilevel ring-stars.

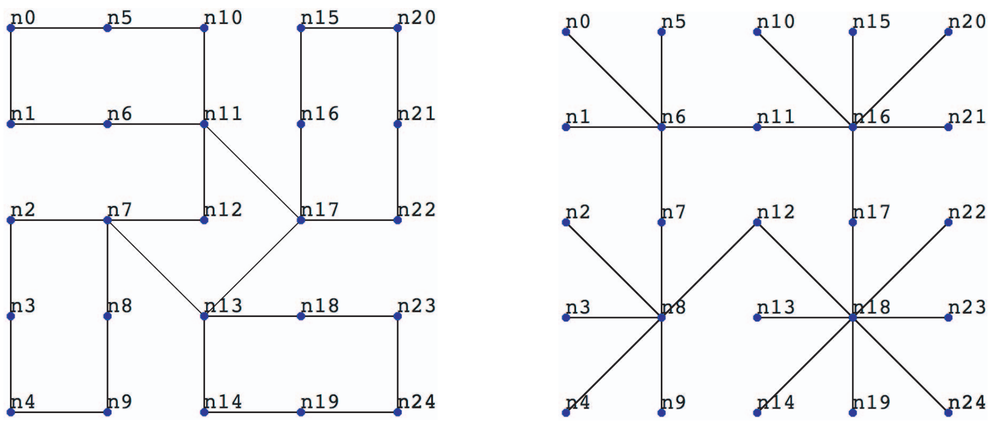


Figure 3. Topologies a) multilevel rings (rings), b) multilevel ring-stars.

The separation between BSs used in this paper is 120 m considering that the typical average length of a street block in large cities is 100 m. We will assume that each base station is at the corner of every street intersection in a rectangular grid of streets. The availability calculations consider the reference distance of 120 m between base stations. Now, the number of wavelengths in a fiber link depends on the number of BSs that a given link is interconnecting to the central station. The number of wavelengths at every link is topology dependent and traffic dependent and requires a wavelength assignment mechanism which is beyond the scope of this paper. In this paper we are limiting the availability analysis to the case of considering the probability that the central node communicates with the end user of the network.

3. AVAILABILITY

The *availability* of service is an important issue in today's networks [14]-[21]. In the case of a link or node's component failure, several communication connections will be affected. To guarantee a desired level of communication service availability, the network must be analyzed in an integrated manner. The calculation of availability is done through the availability maps [1], [20], [21] that are a function of the connection length and of the number of nodes traversed. They provide results to visualize the combined influence of node and link failures on the connection availability in a network. The connection availability is calculated by the following equation [1], [20], [21]:

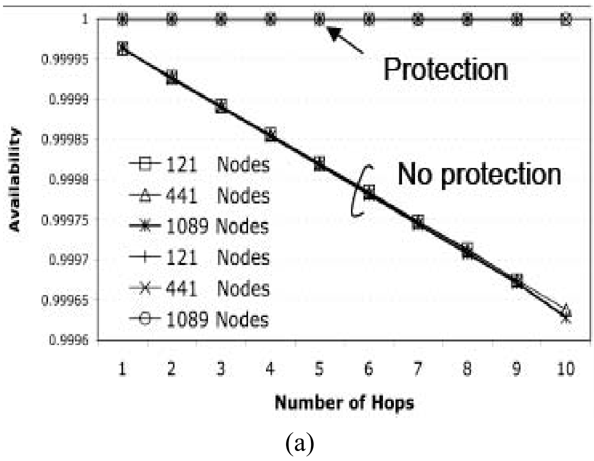
$$A_c = 1 - \begin{pmatrix} AP_{link-km} d + AP_{drop} + AP_{add} + AP_{pass-through} ceil\left((H-1)\left(1-P_{reg}\right)\right) \\ + AP_{reg} floor\left((H-1)P_{reg}\right) + AP_{BS} + AP_{blocking} + AP_{handover} + AP_{RF\_transmission} \end{pmatrix} \quad (1)$$

where $AP_{link\text{-}km}$ is the link availability penalty per kilometer, d is the connection distance in kilometers, H is the number of hops traversed by the connection, AP_{add}, AP_{drop}, $AP_{pass\text{-}through}$ and AP_{reg} are the availability penalties due to adding, dropping, passing through, and regeneration node operations, respectively. P_{reg} is the fraction of nodes in which the connection is regenerated. The functions ceil(x) and floor(x) are the ceiling and floor functions, respectively. AP_{BS}, $AP_{blocking}$,$AP_{handover}$, $AP_{RF\_transmission}$ are the availability penalties due to base station components, call blocking, handover, battery, and RF transmission issues like rain attenuation. In general, the availability penalty imposed by a system can be derived from its failure rate (*FR*) in *FIT* (1 *FIT* = failure rate of 1 failure in 10^9 h) by the following equation:

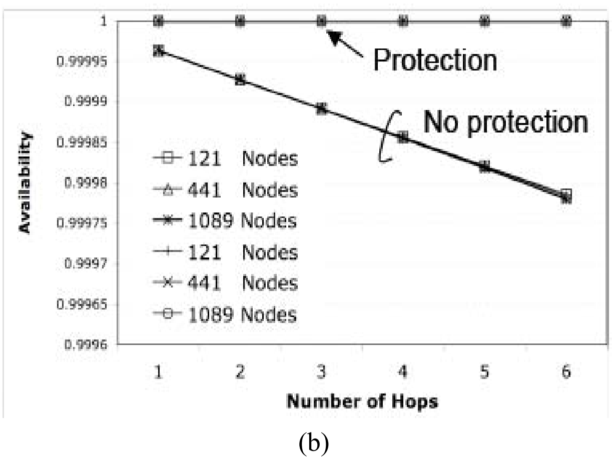
$$AP = 10^{-9} FR \cdot MTTR \quad (2)$$

where *MTTR* is the mean time to repair (in hours). This paper assumes a link failure rate of 310 *FIT*/km [20]. Here we do not consider Raman-pumped amplifiers and we only consider optical Erbium doped fiber amplifiers (EDFAs). The link MTTR was assumed to be 12 h and the node components MTTR is assumed to be 6 h [21]. These values may vary from operator to operator; nevertheless, this assumption does not have a strong impact on the quantitative availability results.

We present results of *fiber network* availability versus number of hops in Fig. 4. Results are for the multilevel rings and for the multilevel ring-stars topologies with 121, 441, and 1089 nodes for the unprotected and protected schemes. Fig. 4 presents results of availability against number of hops.



(a)



(b)

Figure 4. Availability against number of hops for a) multilevel-rings and b) multilevel ring-stars topologies for networks with and without protection with 121 nodes, 441 nodes, and 1089 nodes.

For the multilevel-rings topologies we used 10 nodes per internal ring and 10 nodes per outer ring and for the multilevel ring-stars topologies we used 10 nodes per internal ring and 10 nodes per outer star. The internal rings are the ones that interconnect the central node with one node of the outer rings/stars. Note that multilevel ring-stars topology (Fig. 4*b*) has the advantage of requiring a lower number of hops to reach the nodes compared to the multilevel-rings topology (Fig. 4*a*). Also, the multilevel ring-stars topology has the advantage that it is relatively easy to "grow" when a new node is required in a certain location. Availability results are an average of the availability of nodes that have the same number of hops to and from the central node. We quantify the availability parameter from the central node to all the other nodes and then compute the availability average among all the nodes that have the same number of hops from the central node. Note that the availability for the unprotected case becomes worse with the number of hops and the availability is lower than the *'five nines'* standard for both topologies. If the network is protected with the 1+1 scheme the availability improves considerably and results are greater (i.e., better) than *the 'five nines' (99.999 %)* standard of network availability for both topologies.

3.1. Atmospheric attenuation and rain attenuation

One of the limiting factors inherent in the use of millimeter waves (30 – 300 GHz) is the considerable *atmospheric attenuation* caused by absorption phenomena due to rain drops, water vapor and oxygen. In this section we provide concise results of the limits of propagation at 60 GHz. Fig. 5 shows the received power versus wireless path length by assuming gain transmission antennas of 50 dBi and 20 dBi for the antenna at the BS and 0 dBi for the user's phone antenna. For the calculations, 60 GHz free space propagation loss and maximum gaseous attenuation within the 60 GHz band (15.5 dB/km) are assumed. To implement the wireless link availability with respect to rain attenuation under different weather conditions, the following sample rain data were chosen (99%, 1.3 dB/km, 99.99%, 10.1 dB/km; 99.999%, 32.5 dB/km) [13],[22],[23].

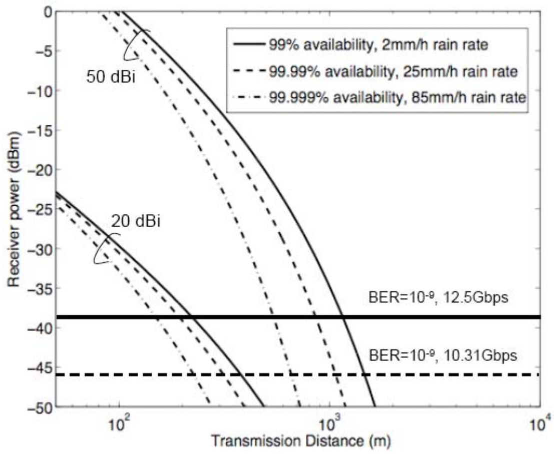


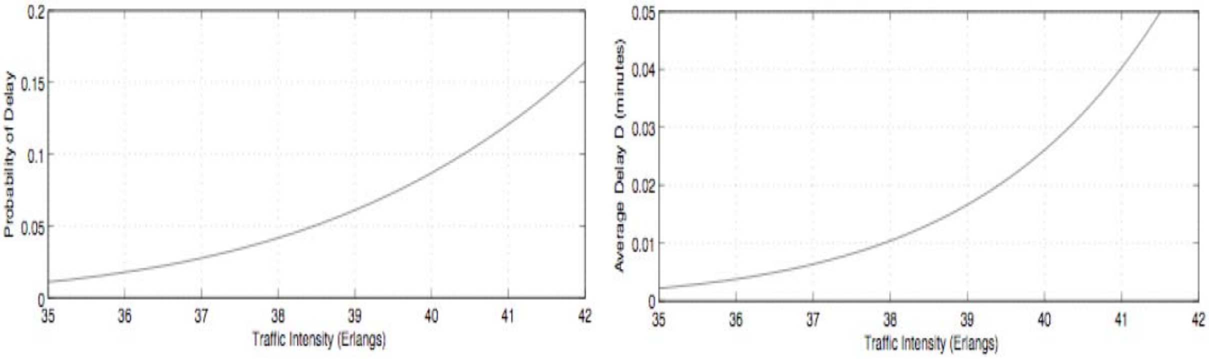
Figure 5. Maximum wireless path lengths under different weather conditions.

3.2. Call blocking

Blocking is produced because there are a finite number of channels in a cell and they are not available. We assume that the wireless systems is one in which a queue is provided to hold calls which are blocked. If a channel is not available immediately, the call request may be delayed until a channel becomes available [24]. This type of trunking is called blocked calls delayed. It is possible to find the failure rate in FIT produced by the call blocking and also its availability penalty. Assuming that the average number of calls per day is 3. Therefore the availability penalty will be given by the following equation.

$$AP_{blocking} = 10^{-9} \quad \frac{\Pr[delay > 0] * 3calls / day * 10^{9}}{24hrs} \quad Dhrs \tag{3}$$

Where Pr[*delay* > 0] is the likelihood of a call not having immediate access to a channel and is delayed. *Dhrs* is the delay time in hours. Fig. 6*a* shows the probability of delaying a call and Fig. 6*b* shows the delay in minutes against traffic intensity for a wireless system with 50 channels. If we consider the load intensity of 40 Erlangs then the probability of delay is 0.087, this gives an average delay of 0.026 min. Therefore the availability penalty due to blocking is $AP_{blocking} = 4.712\times10^{-6}$.



(a) (b)

Figure 6. Probability of delaying a call (a) and the delay in minutes (b) against traffic intensity.

3.3. Call handhover

The handover procedure is a challenge in pico cells due to high-speed users. Assuming a 100 m diameter cell size and a user running at a speed of 100 km/h, his phone will request a handover every 3.6 s approximately, additionally the overlapping area between two adjacent cells is about 10 m, therefore handover must be done within 0.36 s. Also if we consider a call duration of 3 min, the number of handovers is in the order of 40 to 50. This example suggests that a fast and simple handover procedure is indispensable in contrast to conventional mobile cellular networks, where cell size as well as overlapping region is considerably large and there is enough time to perform a handover. The handover procedure is different compared to the one of making a new call. In general, dropping of a call in progress is more problematic than blocking of a new call. There is one method that uses guard channels with first-in-first-out queue (GCM-FIFO) where in a cell with C channels, G_{ch} channels are exclusively reserved for handover [25], [26]. If $(C - G_{ch})$ channels are occupied, new call arrivals are blocked, whereas handover call arrivals are served until all the guard channels in the cell are occupied. Handover arrivals that do not find free channels are queued in a FIFO queue. If a queued handover call does not get service before its waiting time in the queue expires, this call is dropped. However, while the queued calls wait for a channel to be released in the new cell, they still get served from their old base station. Today's standard for one handover failure probability is 0.002. If we consider the worst case of 50 handovers in a call of 3 minutes and 3 calls per day the availability penalty will be given by the following equation.

$$AP_{blocking} = 10^{-9} \quad \frac{0.002 * 3calls * 50 * 10^{9}}{24hrs} \quad Dhrs \tag{4}$$

Therefore the availability penalty due to handover is $AP_{handover}$ = 0.0125 *Dhrs* which is an important issue because it strongly affects the reliability of the system if the delay to establish communication D is greater than 100 ms voice quality of service delay. Also, it is important to mention that a modification of the GCM-FIFO is required to one that stores new calls blocked and handover requests failures to a second queue that gives priority to handover requests over new calls. Future work should consider these modifications to the GCM-FIFO method.

4. CONCLUSIONS

The emerging vehicular applications such as active safety, infotainment, interactive games, and wireless Internet access might dictate very high reliability and availability in future radio over fiber networks. This paper provides an integrated analysis of availability of the optical fiber network and the wireless network, in future radio over fiber systems. We present an integrated comparative analysis of network topologies for radio over fiber networks. In particular, we present results that compare different topologies such as multilevel rings and hybrid multilevel ring-stars in terms of availability. Protection schemes are also considered and results on the protected versions of the aforementioned topologies are also presented.

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