WIRELESS DISTRIBUTION VIA FIBER-OPTIC TECHNOLOGY

J. K. Plourde

Bell Laboratories Research - Lucent Technologies Inc.
9999 Hamilton Boulevard
Breinigsville, PA 18031-9359

(Invited)

ABSTRACT

Fiber-optic technology is expected to continue its explosive growth into the next decade as communications service providers expand capacity. This paper presents an overview of one of these applications for fiber-optic technology, the distribution of wireless signals. Both analog and digital transmission methods can be used. The analog transmission method is emphasized here, and falls into the subcarrier multiplexed category, where the carrier is the optical signal. Digital transmission will be briefly reviewed only sufficiently to put the analog method into context.

INTRODUCTION

Wireless applications are forecast to continue growing at a 25%/yr rate well into the next century. Future wireless is expected to carry most of the telecommunications and will be an important component of voice, fax, e-mail, internet access, and data networking services. Cellular and PCS will be a significant part of this wireless landscape. Wireless frequency allocations vary from country to country, but a bandwidth extending to 2GHz will cover both cellular and PCS services and 2.5GHz will cover LANs, i.e. with exceptions, the analog and digital cellular bands are located around 850MHz, the PCS bands are located just below 2GHz, and wireless LANs are found just under 2.5GHz.

Various technologies can be effectively used for the distribution of wireless signals. These include twisted pair at baseband data rates, coaxial cable at either direct or down converted frequencies, free-space propagation at either direct or mm wave frequencies, and optical fiber, the subject of this report. All these technologies are expected to be advantageously employed for wireless distribution since the optimum choice varies with the needs of a particular application. As an example, for the relatively short distances found in a PBX system containing additional wireless voice channels, twisted pair, coax, or both may be the optimum choice. Conversely, for a larger campus environment, office, or factory building, optical fiber may be the best choice. In addition, decisions can be dominated by non technical issues, such as the cost and availability of dark optical fiber, often the case for the interconnection of an outdoor wireless cell.

Optical fiber is in widespread use in both digital and analog transmission. It offers the well known advantages of low optical loss (<0.5 dB/km) and large bandwidths. Its small size and immunity from electromagnetic interference provides cabling and bundling advantages. Digital methods prevail for both long haul terrestrial and undersea applications. Information capacity is enormous in the dense wavelength-division multiplexing (WDM) systems which are starting to be deployed. Single fiber systems operating at high bit rates at multiple wavelengths for aggregate capacities of up to 100 Gbits/sec over distances of hundreds of kilometers have been announced. These fiber

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systems are continuing their march from long haul applications, through loop feeder, and towards the home as cost continues to fall. Analog methods, by contrast, have features uniquely suited for the distribution of signals including wireless signals. They are widely used in hybrid fiber coax (HFC) systems for CATV distribution and for specialized point to point applications. For HFC, linearity requirements depend upon factors such as the number of channels to be accommodated and can be severe, requiring the use of high performance, temperature controlled, optically isolated, DFB laser modules, often with electrical predistortion.

For reasons of spectral conservation, terrestrial wireless systems are configured into cells, thus requiring large numbers of interconnections to networks. In addition, the extension of coverage to buildings and shadowed areas or the increase of system capacity via the reuse of frequencies, may require further division of cells into sectors, microcells or picocells. The choice is wireless distribution via remote antennas versus remote radio units or perhaps a combination or intermediate solution. In HFC systems, one laser module can serve many hundreds of customers and thus the cost of higher performance components can be justified. Conversely, each microcell or picocell serves fewer customers, especially for indoor systems, and low cost is essential. An important advantage of the analog method (remote antenna), especially for indoor systems, is that the RF spectrum is transmitted unchanged, thereby requiring no upgrade to accommodate new RF bands or protocols as they are deployed, i.e. the fiber connected microcell is transparent to the wireless system.

Digital approaches can also be used to form a linear link by downconverting, digitizing, serializing and transmitting over single mode or multimode fiber with the process reversed at the other end. Digital transfer, while more complex, can take advantage of the availability of standard low cost data-com components. While costs for a stand alone link of this type are higher than for the simple direct analog method, this approach may be competitive in some cases, depending upon system partitioning.

ANALOG DISTRIBUTION EXAMPLE

An example of an indoor microcell design will be illustrated to describe various considerations and the performance required for components. Ignoring important but ancillary functions such as powering, alarming, filtering, etc., a low cost analog link can consist of a laser module with drive and control electronics, optical fiber, and an optical detector with associated electronics[1,2]. For two way communications, these components are duplicated and partitioned into base and remote units and a means for base unit fan-in and fan-out, and remote unit cascading may be included. The up and down links in the remote unit are normally connected through a duplexer to a common antenna (Figure 1).

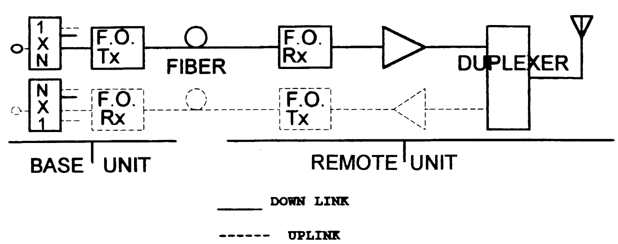

FIGURE 1. MICROCELL BLOCK DIAGRAM

The allowed RF dynamic range in the up link depends on the assumed propagation conditions, antenna characteristics, the presence of unwanted carriers, and the quality of service to be offered. The RF dynamic range together with the assumed number of carriers drives linearity specifications and hence strongly influences cost. While the filtering of unwanted signals is an important consideration, high selectivity filtering of out of band signals may

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not fit within the space or budget of a low cost remote unit.

In general, the uplink is a more severe environment than the downlink. Table I shows a simplified example of an uplink spreadsheet analysis which can be useful to explore component performance tradeoffs. Second order intermod products fall out of band for narrow band wireless applications and are neglected. Laser linearity is represented in terms of the two tone input intercept point in terms of the modulation index, m, rather than the usual parameters of C/N and the composite triple beat (CTB) for the intended number of channels.

UPLINK ANALYSIS	-	-	-
	MAX P	MIN P	ALT. CH
RF, MOBILE TO REMOTE UNIT	-	-	-
RF POWER (600MW=27.8dBm) (dBm)	28	28	28
RF CNR AT CANISTER (dB)	97	80	NA
	-	-	-
OPTICAL, REMOTE UNIT TO BASE	-	-	-
ASSUMED AVG LASER POWER (dBm)	-4	-4	-4
ASSUMED OPTICAL LOSS (dB)	-4.00	-4.00	-4.00
RECEIVED AVG. OPT. PWR (dBm)	-8.00	-8.00	-8.00
OPT.MOD. DEPTH/CH, m (dB)	-51.0	-68.0	-23.0
OPT. Rx AMP. NOISE FIGURE (dB)	3	3	NA
Rx P/CH AT AMPL. INPUT (dBm)	-85	-102	-57
TH. NOISE P/CH AT AMP INP. (W)	2.4E-16	2.4E-16	NA
AVG. PHOTO CURRENT AT Rx (A)	1.3E-04	1.3E-04	NA
SHOT NOISE POWER/CH (W)	6.1E-17	6.1E-17	NA
ASSUMED LASER RIN VALUE	1.0E-14	1.0E-14	NA
LASER RIN NOISE/CH AT Rx (W)	2.4E-16	2.4E-16	NA
TOT. NOISE/CH, OPT. LINK (dBm)	-123	-123	NA
P/CH AT Rx AMP OUTPUT (dBm)	-85	-102	-57
OPT. LINK CNR, AT m VALUE (dB)	38	21	NA
	-	-	-
UPLINK, RF AND OPTICAL	-	-	-
TOTAL NOISE EXCL. INTMOD (dBm)	-123	-123	NA
CNR@REMOTE EXCL. INTMOD (dB)	38	21	NA
	-	-	-
INCLUDE ALT CH INTMOD	-	-	-
IP3 IN TERMS OF m (dB)	10.0	10.0	10.0
C/(TWO-TONE) AT m (dB)	122	NA	66
CNR INCL. INTERMOD (dB)	38	21	NA
CNR INCL. ALT. CHAN. INTMOD (dB)	35	18	NA

TABLE I. EXAMPLE OF UPLINK ANALYSIS FOR 850MHz CELLULAR

This intercept point representation, Figure 2, is useful in that it provides insight into linearity performance, where the minimally acceptable C/N value establishes the low end of the useful dynamic range and the high end is determined by the presence of intermod products which project through the noise floor. Thus the available spur-free dynamic range is in practice an important performance limitation. Intermod products can fall in band and are especially problematic when they interfere with a low level carrier. Thus, performance can be represented as above in usual electrical terms as gain, noise or noise figure and IIP3, or equivalently in usual fiber optic system terms as C/I and C/N for specified BW and operating conditions and be translated from one to the other. Note that the spur-free dynamic range increases 2/3 dB for every 1 dB reduction in noise, increases 2/3 dB for every 1 dB increase in IIP3, or equivalently, increases 1/3 dB for every 1 dB reduction in intermod product level.

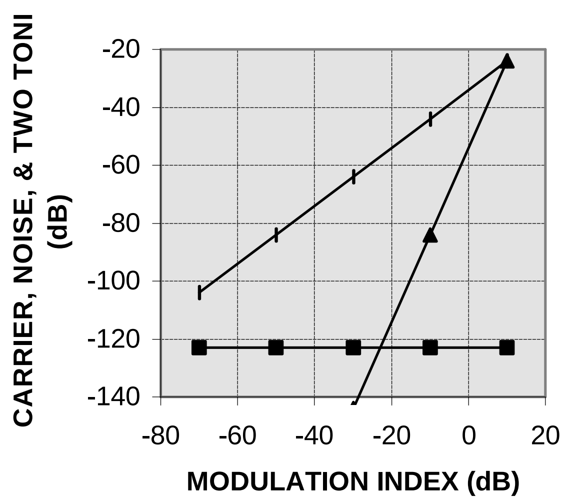

FIGURE 2. IDEAL INTERCEPT POINT

In the spreadsheet of Table I, the various noise terms of interest are the laser RIN, thermal, and shot noise. Much higher performance lasers are available, but the assumption of a third order intercept point of m=10dB in this example provides a spur-free dynamic range of 66 dB which is adequate to provide an overall C/N=18 dB, as required for cellular. In practice additional margin is required for manufacturing variations.

Assumed system conditions can drive the required linearity from values easily obtained with low cost, unisolated Fabry-Perot lasers to values unattainable at any cost. For example, the RF dynamic range depends upon the indoor RF propagation environment (building construction and architecture) and the spacing of microcell antennas; Also, the level of desired system robustness is an issue. Robustness in an 18 channel interfering environment (equal power assumed) adds an additional 26 dB effect beyond the equivalent two-tone assumption.

CONCLUSIONS

Wireless signals can be distributed via subcarrier multiplexed fiber-optic systems. This method is especially attractive for indoor applications since the fiber network is transparent to the system and thus no upgrade is required to accommodate new RF bands or protocols as they are deployed. An example of an uplink analysis for the cellular band was presented. It is important to note that the fiber network can be specified in terms familiar to the wireless engineer. Care must be exercised in specifying the allowed RF dynamic range and system robustness (worst case assumptions) to allow the use of low cost lasers.

REFERENCES

[1] T.S.Chu and M. Gans, "Fiber Optic Microcellular Radio," IEEE Trans. Veh. Technol., vol.40, pp. 599-606, Aug. 1991.

[2] L. Greenstein et al., "Microcells in Personal Communications Systems," IEEE Communications Magazine, pp. 76-88, Dec. 1992.

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