MULTIPOINT™: A MILLIMETER WAVE SYSTEM FOR QUICK ACCESS TO THE INFORMATION SUPER-HIGHWAY

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Abstract-- Broadband wireless service is a natural progression of wireless technology. First cellular and then Personal Communications Services (PCS) demonstrated the advantages of wireless communications for mobil users. However with the deployment of wireless technology, other advantages of wireless systems became apparent. The first advantage is the rapidity with which wireless systems can be deployed compared to wired solutions. This was demonstrated through the deployment of not one, but two cellular systems in just over ten years to provide coverage to over 80% of the U.S. population. The second advantage is the lower cost per subscriber for low take rates for the service. These advantages are independent of the mobility aspect of cellular systems. This was demonstrated by the rapid deployment of cellular systems in some countries as the preferred telephony system. The demand for broadband services such as interactive entertainment, video conferencing, high-speed data, etc., has created the need for the Information Super-Highway. The obvious transmission medium of choice is Fiber Optic networks such as Hybrid Fiber/Coax (HFC), Fiber-to-the-Curb (FTTC) and Fiber-to-the-Home (FTTH). However the time and cost to deploy a wired solution, particularly during the early stages of low take rates in a competitive environment, make the economics of a wired broadband digital solution uncertain. A broadband wireless solution provides an alternative which offers the advantages of quick deployment and good economics in low take-rate environments. This paper describes how a 27-30 Ghz system can offer a wireless alternative for broadband digital services.

I. INTRODUCTION

The term **broadband** is relative and is not defined in the "IEEE Standard Dictionary of Electrical and Electronic Terms" (1984). It is generally accepted, however, that voice telephony circuits and conventional two-way radio (including AMPS cellular) constitute narrowband systems In the past, video has been deemed broadband (relative to audio). However, as network transmission bandwidths have increased, the suitability of the term broadband has similarly escalated. For the purposes of this discussion, the term broadband will be used to indicate networks having 100 MHZ or greater bandwidth and capable of supporting data rates in excess of 100 MBPS. Examples of broadband systems include Cable TV (CATV) networks, Fiber Optic networks, Hybrid Fiber/Coax (HFC) networks, wireless cable systems, Direct Broadcast Satellites (DBS) and high-speed Ethernet.

The most ubiquitous broadband network is the HFC network, It can support one-way transmission from 50 - 450 MHZ in almost all deployed systems and can support transmissions (including two-way) from 5 - 1000 MHZ in advanced systems. Variations on the HFC network include Fiber-to-the-Curb (FTTC), Fiber-to-the-Pedestal (FTTP) and ultimately Fiber-to-the-Home (FTTH). The technical choice would be FTTH, but economics favor HFC. Even so, the cost of the coax portion of the HFC network constitutes 80% of the cost. This is because the fiber portion may serve 100 - 500 homes while the coaxial portion must be deployed past every home. Hence "the last mile", i.e., the final distribution portion of the network, represents a high percentage of the investment cost. And this cost must be incurred even if only a small percentage of the homes passed actually subscribe to the service..

A wireless solution can significantly reduce the cost per subscriber. However the bandwidth of a wireless system must be comparable to that of an HFC system, i.e., 500 MHZ or greater, in order to be competitive in terms of services offered. Obtaining access to this much spectrum is difficult and necessitates movement to the upper regions of the radio spectrum. Recent FCC actions have set aside portions of the 27 - 30 Ghz spectrum for Local Multipoint Distribution Service (LMDS). Similar actions are expected in other countries. Unlike DBS and MMDS, LMDS does not restrict the nature of the services offered. In particular, LMDS can provide two-way services for data, voice and video. Only modest restrictions related to interference and co-ordination between licence holders apply. It is envisioned that the spectrum will be used not only for video, but also for quick, affordable access to the

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Information Super-Highway. Never before has such a broad band of radio frequency spectrum been made available for un-encumbered deployment of wireless services.

II. THE NATURE OF 28 GHZ WIRELESS PROPAGATION

It is necessary to move to the upper regions of the RF spectrum for two key reasons: (1) Most of the spectrum below 26 Ghz has already been allocated for specific services; and (2) The size of the antenna becomes much smaller for a given performance requirement as frequency increases The importance of the later reason will become more clear in the following discussion

Numerous papers on the use of 28 Ghz for broadband communications describe experimental results on propagation at these frequencies. The 28 Ghz band remained essentially unused until Cellular Vision filed a petition to re-allocate portions of the 28 GHz spectrum for LMDS in 1987. The initial application provided television service to subscribers using analog FM modulation of video at 28 GHz Work by the author and colleagues at Texas Instruments have shown that the concept can be extended to provide two-way digital transmission to transport digital data and voice as well as digital video to provide a wide range of services to both business and residential customers. However, there are two major disadvantages to operation at 28 Ghz The first is the significant attenuation due to rain at 28 Ghz The second is the significant excess attenuation by foliage The effect of rain is well documented in published tables (CCIR).. The effect of foliage has been experimentally evaluated by TI (and others) recently. Analytical results indicate that reliable (99 9% link availability) can be achieved at 28 Ghz with QPSK modulation when using one Watt per carrier for channel bandwidths up to about 50 MHZ and for cell radii in the range of 3 - 5 km. Published literature suggest that reliable propagation through foliage is not practical without resorting to unduly large Effective Isotropic Radiated Power (EIRP). Thus in effect, propagation at 28 Ghz is quasi-optical, i.e., truly Line-of-Sight (LOS) Testing by the author and colleagues at Texas Instruments, as well as others in the field, verified these findings. While it has been suggested that non-LOS propagation is possible by using reflections from buildings or other reflectors of opportunity, testing at Texas Instruments indicate that, although possible in some cases, it is not a reliable technique. A better mitigation measure is to use multiple overlapping cells to provide better coverage.

Other propagation issues include self-interference (from the same node via multi-path and from adjacent nodes), loss through glass and other materials, loss due to ice and snow and de-polarization in the presence of rain. Testing at TI produced the following results. (1) Interference due to multi-path reflections is minimal, particularly when using QPSK modulation or FM. Most objects are sufficiently rough to scatter waves at 28 Ghz. (2) Self-interference from adjoining nodes or cells is minimized by the use of highly directional subscriber antennas. Use of subscriber antennas having narrow beamwidths and sidelobes greater than 25 dB down from peak of beam significantly reduce interference from adjoining cells The use of orthogonal polarization in adjoining cells further reduces adjacent cell interference. The use of QPSK modulation with substantial error correction capability provides significant tolerance to interference. (3) Many glasses which contain metal films to reduce heat transmission also significantly attenuate 28 Ghz signals. (4) Wood roofs and wood roofs with composition shingles offer relatively low attenuation when dry, but have very high (30 dB) attenuation when wet, even moderately wet. (5) Snow has relatively low attenuation except when collected in the dish of an antenna Ice, even in moderate amounts, has high attenuation This indicates the need for a radome in areas subject to such weather conditions.

Propagation at 28 Ghz must consider factors other than simple f^2 loss with increasing frequency. However reliable communications can be achieved over ranges of 3 - 5 km in most areas with reasonable power levels and moderately high data rates as long as LOS paths are utilized. Trees are perhaps the greatest limitation for achieving LOS in some residential areas.

III. MULTI POINT™ SYSTEM DESCRIPTION

The development of a broadband two-way digital communications system for reliable operation at MMW (27 -30 GHz) frequencies required the invention of several novel system concepts as well as development of key technologies. Perhaps the greatest challenge was to perform the significant engineering trade-offs to yield a viable, attractive wireless solution for providing two-way broadband digital services to subscribers. Although relatively simple when considered on an individual basis, the trade-offs became more complex when considered in the aggregate. As an example, the optimum system solution is a complex relationship between services offered, capacity, cell coverage, take rates, etc. Coverage is a function of rainfall rates, power output, bandwidth, antenna gain, antenna beamwidth, etc.

The TI MulTIpoint™ system provides a two-way transport solution from the Central Office and/or Head-End to the subscribers TV, telephone or data port. However this paper will concentrate on the RF transmission system only. A block diagram of the basic elements of the RF system are shown in Figure 1. A cell is composed of a Node or base station which serves a large number of subscriber transmit/receive terminals. The system is designed to provide two-way service to subscribers although a one-way variant is comprehended. Cell radius is a function of rainfall rates, availability of Line-of-Sight to subscribers, capacity and other factors, but is nominally 3 - 5 km. Path loss over these short ranges under LOS conditions essentially varies as R^2 and f^2 in clear air (i.e., no rain) conditions; the loss in dB is given by:

$$\text{Loss} = 92\ 2 + 10 \log R^2 + 10 \log f^2$$

where R is in km and f is in GHz. At 28 GHz and 4 km, this is approximately 133 dB. Solid state power amplifiers can provide up to one Watt of transmit power per carrier at the node. A system noise figure of 7 dB can be achieved with a well-designed L.A and receiver. Antenna gains of 12 dB and 34 dB are achievable in the Node and subscriber antennas respectively. By using QPSK modulation and powerful error correcting codes, data rates up to 50 MBPS can be achieved from the Node-to-Subscriber with 15-18 dB of rain fade margin. For the return path (i.e., subscriber-to-Node), cost considerations limit the return power amplifier to about 100 mW of output power. This in turn limits data rates to approximately 2 MBPS in the reverse direction.

A single-carrier per-channel architecture is used to maximize the power per carrier while minimizing sensitivity to amplifier distortion. Although linearity requirements are much less than those needed for a multi-carrier amplifier, the amplifier must be sufficiently linear to prevent the restoration of spectral sidelobes after filtering.

Unlike satellite receivers which receive signals which have relatively constant power, the MulTIpoint subscriber receivers must receiver signals with power variations of 50 dB or more In addition, the received signals are composed of multiple (up to 40) carriers. Hence the LNA must have a wide dynamic range and the receiver must incorporate some form of AGC.

Digital transmission of QPSK signals at 28 GHz must consider Phase Noise in all oscillators. Perhaps the most difficult is the LO in the subscriber receiver due to cost sensitivity The design of stable oscillators at 28 GHz which achieve a phase noise performance better than -100 dBc at 100 kHz from carrier is particularly challenging. Broadband transmission of digital signals at 28 GHz poses other problems. These include minimizing amplitude variations induced by high VSWR, minimizing group delay distortion, achieving adequate Transmit/Receive isolation and minimizing losses at these frequencies.

V. SUMMARY AND CONCLUSIONS

A wireless broadband transmission system which provides "the last mile" for a broadband network offers significant cost advantages over a wired solution when low take rates are expected. A wireless system can be deployed much faster than a wired system, and for less up-front cost. Recent FCC actions have paved the way for a broadband wireless system at 28 GHz which can provide two-way access to the Information Super-Highway for voice, data and video service. MulTIpoint provides the first all-digital, total system solution for these services. Millimeter wave and microwave devices are critical to the system. Broadband digital transmission systems impose some unique requirements on devices for MMW/microwave operation. Such systems can also take advantage of the unique nature of these higher frequencies. The biggest technical limitation on operation at these frequencies is foliage attenuation. LMDS will not replace wired systems, but will provide a viable alternative in many applications.

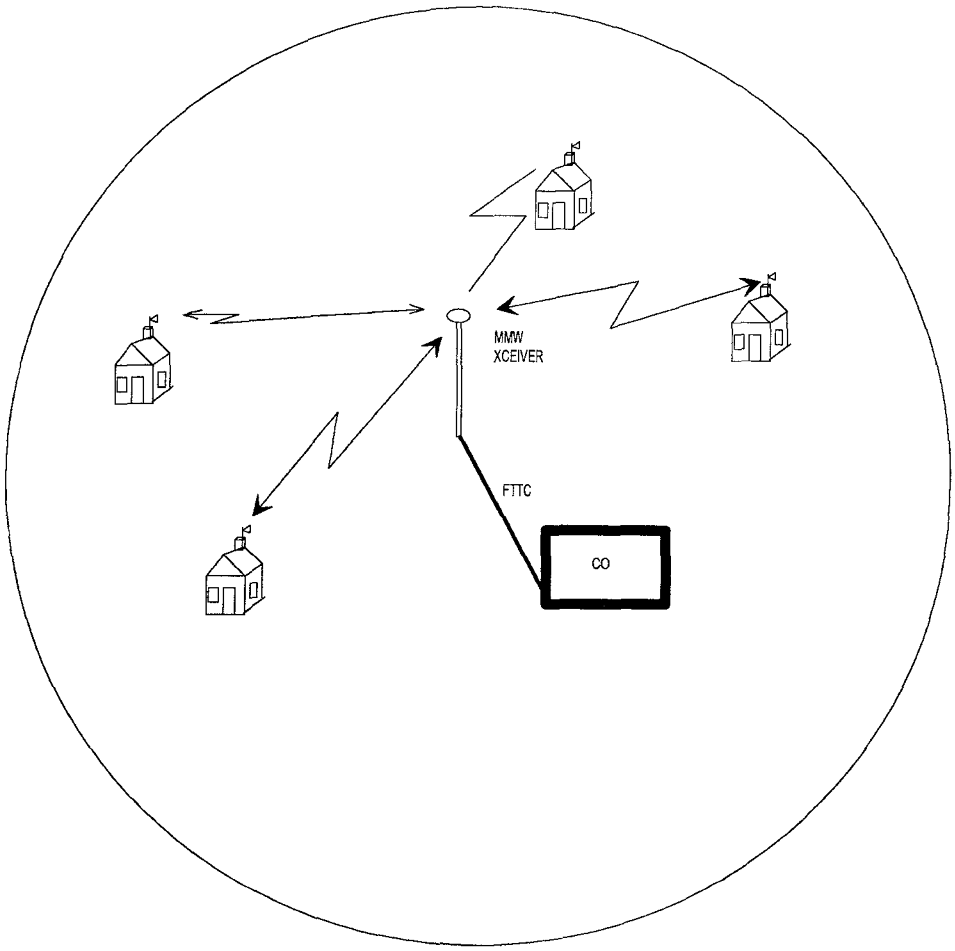

Figure 1. MulTIpoint Cell Configuration