Microwave Radio Link Performance

Microwave radios compare favorably with the cost, performance and reliability of other transmission media

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Due to limited high-speed, fiber-optic systems in the access portion of transmission networks, both fixed and mobile network operators have used microwave radio to overcome the last mile bottleneck. As user services migrate from voice to data, the quality and reliability of microwave radio becomes an issue, particularly given the distortions resulting from rain and multipath effects.

This article shows that not only does microwave radio meet and exceed international carrier transmission standards for data services, but it also is in many ways a more reliable medium than fiber and exceeds the guaranteed reliability of a leased-line circuit.

Introduction

Microwave radio as a transmission medium has been available for many decades. In the past, international carriers used high capacity, multichannel analog microwave radio systems as the main transmission bearer for what was then predominately voice traffic. Gradually, carriers replaced in the core network radio systems with fiber optic links, which combine higher bandwidth with virtually error-free transmission. As more data requirements emerged, the improved quality of fiber optic relegated microwave to second place in the minds of many operators, mainly because fading effects on analog radios had a limited effect on voice but adversely affected the throughput rates of data services. This questioned the suitability of radio for non-error-correcting data standards, such as asynchronous transfer mode (ATM).

With the advent of digital microwave systems in the early 1980s, link quality was dramatically improved but new fading effects, such as selective fading due to signal distortion, placed doubts in operators' minds about the suitability of radio for high quality data connections.

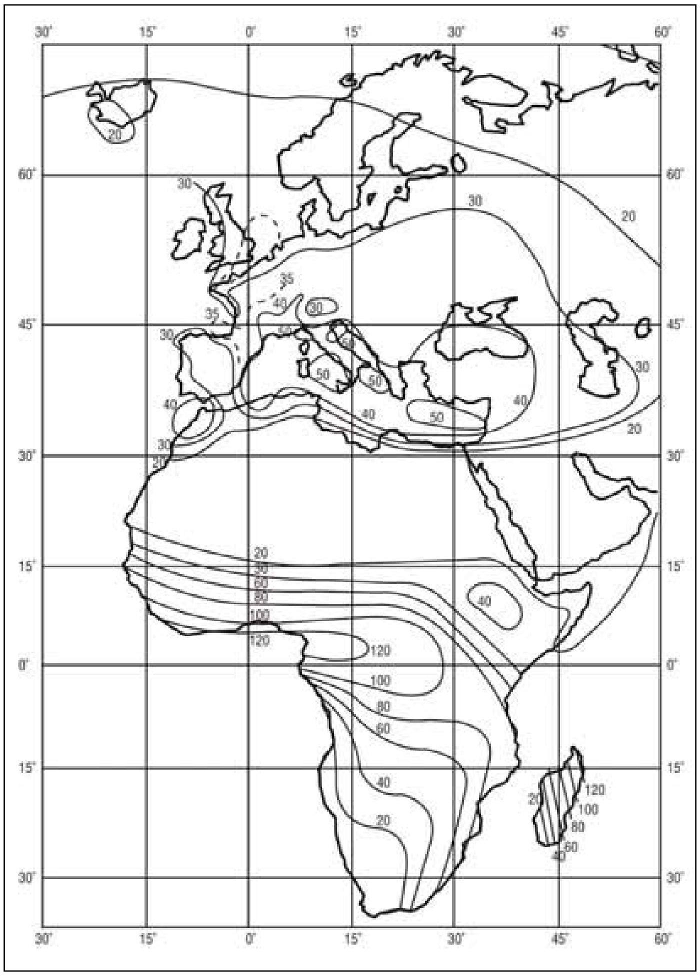
Radio designers soon realized that radios should not only meet the ITU transmission standards, but that they should be designed to have comparable performance to fiber optics. Powerful transversal adaptive equalizers and forward error correction algorithms built into the radio modems now ensure that radio achieves the same inherent bearer transmission quality as fiber (above 10^{-11} up to 10^{-13}).

Despite much evidence that radio systems have comparable performance to fiber in terms of quality, many skeptics still point to the fading effects, such as rain, to argue that radio is less reliable.

Benefits of radio

Before we consider the problems of radio, let us consider what benefits it has. With the Telecom deregulation of the 1990s, cellular operators and alternate carriers, who had aggressive rollout commitments, quickly recognized that microwave radio had many benefits, including:

- Rapid deployment (no servitudes and road crossings).
- Flexibility (can upgrade, increase capacity or redeploy).
- Mixed radios in network (no common hub).
- Easily crossed city terrain (no street digging).
- Operator-owned infrastructure (no reliance on competitors).
- Low start-up capital costs (not proportional to distance).
- Minimal recurring operational costs.



▲ **Figure 1. ITU-R rainfall map.**

- Existing radio infrastructure for cellular radios (cell towers).
- Inexpensive deployment in urban environments (use rooftops).
- No cable cuts.
- Better resilience to natural disasters such as floods and earthquakes.
- Quicker recovery if damaged.

Because fiber was not always available at needed sites, radio often was the only choice left to an operator to connect a new customer or base station to the network. This is not surprising, as fiber networks connect less than 0.5 percent of major commercial buildings in Europe. Although in the US the figure is higher, it is still less than 5 percent. Statistics show that the trend to connect fiber to new buildings is slowing rather than accelerating, due to the high cost of provisioning fiber. Further, some cities, such as San Francisco, have passed bylaws preventing streets being dug up, due to excessive fiber digs after deregulation. In many cases, fiber in the access portion of the network is simply not available.

Fiber is cost-effective in the core of the network where extremely high bandwidths are required. However, in the access portion of the network, where the maximum capacity requirements are typically less than STM-4, radio has an obvious advantage.

Fading on microwave links

Fading can be attributed to two phenomena: multipath and rain attenuation.

Multipath

A microwave signal propagates as a transverse electromagnetic wavefront. Because the top of the beam experiences a different refractive index to the bottom of the beam, the signal is bent upwards or downwards due to refraction. The gradient of refractivity varies according to geographic location and the time of the day and year. The nonuniform nature of these gradients in the lower layers of the atmosphere can result in multiple paths.

Multiple paths can result in disruptions, especially for radio links operating in the lower frequency bands (less than 18 GHz) over longer path lengths (greater than 20 km). Disruption can be numerous short outages (measured in milli- or even, microseconds), usually limited to a fading season of a few months in the year. This type of fading has been well characterized by years of empirical measurements, resulting in proven system design methods that limit outages within international circuit limits. By choosing appropriate antenna sizes and diversity methods, international objectives such as International Telecommuni-cations Union Recommendations (ITU-R) can be met using modern digital microwave systems.

Rain attenuation

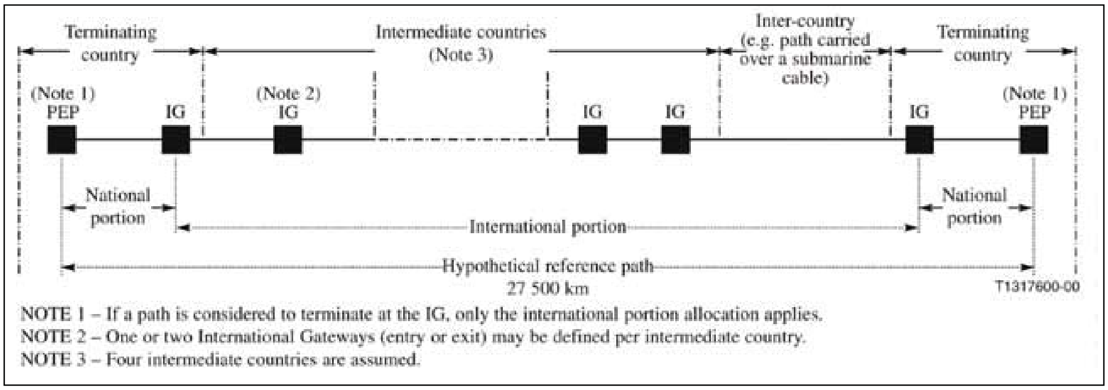
Microwave radio links above 15 GHz tend not to be affected by multipath because link lengths are short due to design limitations imposed by high microwave rain absorption. However, microwave links operating in these frequencies are affected by rain and other forms of precipitation (i.e., freezing fog). Subsequent outages affect the annual availability objective.

Taking into account the severity of rainstorms in a given region, typically each radio link is designed to achieve between 99.99 and 99.999 percent availability. The ITU-R published rainfall maps (see Figure 1) enable designers to predict the expected rain outage. In short, good system design limits rain outage to a predetermined level to meet International Reliability Standards G.827.

Cable reliability

Cable-based systems also experience outages from a number of causes, including:

- Dig ups: 58.1 percent
- Vehicle: 7.5 percent
- Power Line: 4.4 percent



▲ **Figure 2. G.827: Hypothetical reference path.**

- Rodent: 3.8 percent
- Sabotage: 2.5 percent
- Fire: 1.9 percent
- Other: 13.9 percent

The worst-case objective set for a radio link of 99.99 percent is a high figure. In the case of fiber, a single cable cut per year that takes eight hours to restore represents an availability of 99.9 percent. It is unlikely that access fiber will be restored within eight hours. Many fiber systems are unable to deliver the high availability that radio offers.

ITU standards

The ITU Standardization Sector (ITU-T, formerly CCITT), specifies the objectives for an international circuit, using a reference distance of 27,500 km. It is assumed that part of that international connection is via a radio route, for which specific objectives are set by the ITU-R sector (formerly the CCIR).

The overall reference connection, as shown in Figure 2, is divided into the international portion and a national portion, with the section between the local exchange and the end customer (PEP) termed the "access" portion. The ITU publishes these specifications and standards in the form of recommendations.

Radio outage standards and objectives

Outages are discriminated by the ITU, which separates outages that last longer than 10 seconds from those less than 10 seconds and defines availability standards (Recommendation G.827) for the former and performance standards (Recommendations G.821, G.826, and G.828) for the latter, respectively. The generic term for availability and performance is reliability.

In ITU-R F.695, the overall availability standard for radio links is specified as 99.7 percent for a 2,500 km radio section. The objectives derived from ITU-T G.827 are specified for the international portion in ITU-R F.1492, and those for the national portion are specified in ITU-R F.1493.

The radio performance objectives derived from ITU-T G.821 specify that the severely errored second ratio (SESR) should not exceed (L/2500 km × 0.00054) in the worst month (for a 2,500 km radio section).

The radio objectives derived from G.826 are specified in ITU-R F.1092 for the international portion and ITU-R F.1189 for the national portion. The radio objectives derived from ITU-T G.828 are specified in ITU-R F.1397 for the international portion and ITU-R F.1491 for the national portion.

It is not a trivial exercise to derive the radio hop objectives for the access portion of the network from the length-independent objectives specified by the ITU. As radio hops seldom fit neatly into the ITU reference model, which is designed for linking the hierarchy of switches in an international circuit, each operator could come up with a different objective for the individual radio hops, depending on the assumptions made.

Real objectives

Apart from all the theory, an operator's concern is to ensure customer traffic is reliable. This traffic can be carried over various parts of the overall network that will always include the access portion.

A leased line or microwave radio connection forming part of this overall connection would be an apportioned part of the overall objective specified by the ITU such that, when added to the remaining transmission, it will still meet the overall objective.

In the microwave industry radios in routes with hop lengths typically exceeding 30 km are usually referred to as long haul radios. Radios that are deployed in the access portion of the network with hop lengths of typically less than 30 km are called short haul. This is not to be confused with the ITU terminology where long haul in an international standard could be an undersea cable, satellite or fiber optic route, and short haul is the non access portion of the national network up to the switching center, which in microwave radio terms is long haul. Here, we refer to backbone and access portions with respect to availability objectives for microwave radio systems.

Backbone standards

Radio routes that cover many hundreds of kilometers typically use radios in the lower, non-rain affected frequency bands with hop lengths often exceeding 30 km.

Multipath fading is the main outage condition. If strict adherence to ITU standards is required (i.e., for an ATM-based radio transmission system, such as universal mobile telecommunications service (UMTS)), the radios should be designed to ITU-R 1491 (derived from G.828). Compliance to this standard guarantees that the ATM performance standard ITU-T I.356 will also be met.

This means the performance objective for SESR is:

$$SESR = 0.002 * [(A1 + 2 * 10 - 5) \times L]$$

where radio route length exceeds 100 km. $A1$ is provisionally set between 1 and 2 percent.

As a comparison, the objective derived from G.826 is identical. The formula for SESR in G.826 is:

$$SESR = 0.002(A1 + 0.01 * L/500\ km)$$

A 200 km radio route would thus have an objective of 0.0048 percent. Assuming four 50 km hops, each hop would need to meet 0.0012 percent in any month.

This target is achievable using radio, provided the antennas are sized correctly. Fading countermeasures and space diversity equipment configurations are used to further improve the performance on longer hops.

From an availability perspective, the links are not affected by rain (due to the low frequencies used), so primary outages are from equipment failures. Using redundant equipment configurations, such as hot standby protection, the link availability is virtually 100 percent, even on very long routes approaching 2500 km.

In conclusion, backbone radio links can be designed to meet and exceed the G.828 performance objectives, and are well within the expected availability targets.

Access standards

In the access portion of the network, the links are typically less than 20 km and are implemented using greater than 15 GHz radio links. In this case, rain attenuation and not multipath is the dominant cause for outage because rain outages last longer than the 10 second outage condition. This is considered under availability standards or those derived from G.827. The G.828 performance standard is easily met with high frequency hops, as multipath fading is insignificant and performance is again virtually 100 percent with protected equipment.

Rain outage is calculated by predicting the amount of time a rain rate that exceeds the fade margin is exceeded. ITU-R F.1493, derived from G.827, specifies 99.95 percent as the availability objective within the access portion of the network.

Equipment protection

Typically, radio hops are designed to achieve between 99.99 and 99.999 percent availability for rain outage. This objective includes outage from rain and equipment failure. To determine the allowable number of hops in tandem, the equipment protection configuration must be considered. With all hops using hot standby equipment protection so outages due to equipment failure can be ignored, all the outage can be attributable to rain outage. With each hop achieving 99.999 percent, 50 hops in tandem meet a link target of 99.95 percent.

In practice, the network topology is determined and the appropriate protection is assigned. An access availability standard of 99.95 percent can be met using only two hops in tandem and a non-protected radio terminal MTBF of 10 years or better, with each of the links designed to 99.99 percent availability from rain outage. Beyond this, hot standby is required to achieve the objectives. This again demonstrates that for access links, microwave radio easily meets the ITU reliability standards.

Radio versus leased line

Many operators choose leased line as their transmission bearer because they assume that the leased line route is simpler to manage and provides a higher reliability than self-provisioned microwave. In most cases, this is an expensive option and obtaining leased lines for new facilities can take longer than installing a new microwave link.

A comparison between self-provisioned radio and leased line over fiber is given next. Access-type leased line circuits typically offer 99.85 percent availability. We have shown above that a well-designed microwave network achieves typically > 99.95 percent for a multihop system. If required, links can be designed to very high standards by designing to 99.999 percent per hop for rain attenuation and virtually 100 percent link availability using hot standby equipment protection. If the leased line is fiber, a cable break would in most cases exceed the 99.85 percent objective and unless alternate routing of service is available (not common in the access network), the link could be down for many hours, if not days. For radio, an abnormal rainstorm causes an outage for a few minutes.

Apart from the obvious benefits in terms of cost and speed of deployment, radio provides significantly improved reliability with the added benefit that the operator may choose the link reliability according to the application rather than being beholden to whatever the provider supplies.

Data transmission compatibility

Latency

With high-speed data services and transport technologies such as ATM and increased focus on different data types (delay insensitive, unconstrained data delay (UDD) and low constrained delay (LCD)), the end-to-end delay over a network is a critical design factor. ATM switches introduce up to 2 msec delay and there is a concern about the number of times ATM compression can be used in a tandem link before the overall delay objective is exceeded. For example, the end-to-end delay allowable from the user equipment (UE) to a UMTS radio network controller (RNC) is 7 ms.

Microwave signals travel as an electromagnetic wavefront. The speed of propagation is dependent on the dielectric constant of the medium. The dielectric constant of air is almost unity and the signal travels at the speed of light (3×10^8 m/s). The propagation delay of microwave radio is thus essentially no different for fiber. There is of course the processing delay through the radio repeaters, but with TDM technology, the typical buffer delays are only tens or hundreds of microseconds. The main processing delay in microwave is the forward error correction (FEC) buffering, which decreases the higher the capacity of the radio link. Consequently, microwave radio introduces a negligible end-to-end delay into data networks and can be effectively ignored.

Timing (jitter/wander)

Errors introduced through normal jitter and wander effects were addressed by the availability and performance standards discussed above. Additional network timing issues, such as those introduced by the inclusion of synchronous digital hierarchy (SDH) multiplexers, must be considered separately. The SDH frame synchronization method uses a technique called pointer adjustments. The pointer is an address field that tells the multiplexer where the virtual container (VC) is located within the overall frame. Adjusting the pointer address to inform the multiplexer that the VC position has moved can rectify any real delays that occur over the network. The pointer addresses are moved in blocks of 3 bytes, so each pointer movement adds 3 unit intervals (UI) of jitter onto the system. ITU-T G.822 sets the overall limits on jitter and wander in a network. The clock stability of the timing sources is specified in a hierarchy of standards as defined in ITU-T G.811 (primary reference clock), G.812 (secondary reference clock) and G.813 (synchronous equipment clock).

The hierarchy specifies that a maximum of 20 network elements (NEs) from the primary reference clock can be daisy-chained until it needs to be filtered to the stability set in G.812. After 60 NE's, the clock source must be regenerated to achieve a G.811 standard. External synchronization equipment, often global positioning system (GPS)-based, is used to achieve this in a network. Add-drop multiplexers must meet the objectives laid down by G.813.

If an SDH radio reframes the signal, a synchronization port to ensure it can be synchronized to the external clock source should be offered. Traditional SDH radio is able to provide synchronization options to enable the radio to run in multiplexer section termination (MST) mode, where the relevant overhead bytes are terminated and equipment is timed by either external 2 Mb sources or from an internal clock with a defined accuracy. MST is only needed when an external multiplexer is not used and is rarely used in practice.

More recent synchronous radios on the market, including the Altium from Stratex Networks, provide a transparent transmission pipe, which in SDH terms runs in a default regenerator section termination mode (RST). In this mode, the radio obtains synchronization from the aggregate 155 Mb input into the radio. Consequently, the Altium does not offer or require any synchronization options.

Conclusion

Microwave radio is a cost effective and practical option for transmission solutions in all parts of a fixed or mobile network, including applications for backbone, backhaul and access.

Microwave radio links can be properly and precisely engineered to overcome potentially detrimental propagation effects. Compared to alternative wired infrastructure, microwave will meet strict reliability standards. In particular, compared to leased transmission circuits from existing incumbents, where reliability guarantees are low or non-existent, microwave radio standards offer a compelling alternative, with low start-up costs and minimal ongoing operational expenses. ■

Author information

Trevor Manning received a bachelor of science degree in electrical engineering from the University of Natal in Durban, South Africa, in 1984. After graduation, he worked with the South African national electricity utility (ESKOM), where he was involved in radio system design and site selection for the SDH digital upgrade for ESKOM's $100 million radio network. In 1991, he worked for Telettra in Vimercate, Italy, with world-renowned propagation expert Umberto Casiraghi. He has traveled extensively visiting with engineers in the telecommunications field and has presented a number of technical papers at various conferences. Currently, he is employed by DMC Stratex Networks as technical director within the marketing department of the Europe, Middle East and Africa sector, based in Coventry, UK. He may be reached via E-mail: Trevor_Manning@stratexnet.com; or Tel: 44-24-7651-4320.