HAPTER 8

Wireless Modulation Techniques and Hardware

pon completion of this chapter, the student should be able to:

- Discuss the general characteristics of wireline and fiber-optic transmission lines.
- Discuss the propagation conditions peculiar to the air interface for wireless mobile systems and wireless LANs.
- Discuss the coding techniques used by wireless mobile systems to combat transmission errors.
- Explain the basic fundamental concepts of digital modulation techniques and their advantages.
- Explain the basic operation and characteristics of spread spectrum modulation systems.
- Discuss the basic principles behind the operation of ultra-wideband radio technology.
- Explain the theory behind the use of diversity techniques for the improvement of wireless communications.
- Discuss the typical BSC and RBS hardware found at a modern cell site.
- Discuss the technical attributes of a subscriber device.

8.1 TRANSMISSION CHARACTERISTICS OF WIRELINE AND FIBER SYSTEMS

Fixed telecommunication infrastructure takes on many forms and uses many different techniques to transmit information from point to point. Depending upon the distance, form of the information (analog or digital), required data transmission rate, and the environment that needs to be traversed, one might choose from any one of many different technologies to deliver the desired signal or signals from one point to another. For either relatively short or extremely long fixed terrestrial point-to-point networks, one typically finds some form of guided-wave transmission media used. The physical implementations of these media are commonly known as transmission lines. Although today one can point to numerous examples of short-haul, fixed point-to-point radio links that have recently come into their own in terms of popularity, this section will limit its coverage to conductor-based (wireline) and fiber-optic transmission lines. A brief overview of the common types of transmission lines and their characteristics follows. In all cases, these types of transmission media provide a more reliable channel than the typical wireless radio channel.

Conductor-Based Transmission Lines

$x_c = \frac{1}{2\pi f c}$ $f_c = \frac{1}{2\pi RC}$ $X_C = \frac{1}{2\pi f C}$

The purpose of a **transmission line** (TL) is to guide a signal from point to point as efficiently as possible. At low frequencies (with extremely long wavelengths), current flows within the conductors and is not prone to radiate away from the TL. At higher frequencies, the current flow takes place near the conductor surface (due to the so-called skin effect). At radio frequencies (RF) and higher (microwaves and millimeter waves), the transmission line acts as a structure that guides an electromagnetic wave (EM). Many specialized TLs exist for use at these extremely high frequencies but will not be discussed here.

There are numerous types of TLs available for use in today's telecommunication links. Some of the more commonly encountered **wireline** TLs are unshielded and shielded twisted pair (UTP and STP), LAN Category-n cable, and coaxial cable. These cables are used to provide the local-loop connection to the telephone central office, LAN connectivity, and broadband cable TV service to name just a few applications. In all cases, wireline transmission lines act like low-pass filters, their signal attenuation increases with frequency. The individual characteristics of these wireline cables provide differing levels of bandwidth, maximum transmission rate, and reliability. Therefore, when designing a new telecommunication link or choosing what type of TL to use, one should choose a TL designed for that particular application.

In general, the most important TL characteristics to consider are bandwidth, susceptibility to noise, and frequency response. For the cases of bandwidth and frequency response these characteristics are fairly stable with time and can be designed around or adapted to by intelligent systems (ADSL, HDSL, etc.). These types of systems test the link to determine its initial characteristics and adaptively adjust their operation before attempting to use it. They continue to test the link periodically thereafter and adapt to any changes as necessary. TL susceptibility to noise is another issue. Different twisted pairs within a binder of multiple pairs can have varying amounts of ingress of near- and far-end cross talk (NEXT and FEXT noise) associated with the pair depending upon the various types of traffic being carried on the other pairs within the binder. Also, the existence of other nearby or not-so-nearby electrical noise sources (atmospheric, man-made EMI, etc.) can also impair signal transmission. Coaxial cables offer the advantage of shielding as do various types of shielded twisted pairs. Shielding allows the coaxial cable to be placed in environments that are unfavorable to simple unshielded transmission lines. However, for both coaxial cable and STP, noise ingress can occur at termination points, splices, or connectors. To compensate for these facts, various coding schemes and transmission protocols have been developed to respond to the ultimate result of too much noise, bit errors, or frame errors in transmitted data. Use of these error detection and correction schemes tends to provide reliable data transport over wireline TLs.

Fiber-Optic Cables

The ultimate telecommunications transmission media is the fiber-optic cable. Besides having a potential for almost unlimited bandwidth, it is not susceptible to electromagnetic interference (EMI) and its physical construction typically blocks any ingress (or egress for that matter) of stray photons that could cause problems. It is not that fiber-optic cables do not have any noise problems, it is just that the noise is quantum in nature. Therefore, if the optical detector used at the far end of the optical link has a sufficient number of photons reaching it, the bit error rate (BER) will be extremely low and for all practical purposes is nonexistent. In fact, other components in the fiber-optic link (sources, detectors, amplifiers, optical switches, etc.) may contribute more to the generation of noise and bit errors than the cable itself. This fact has led to the popularity of using fiber-optic cables for long-haul, high-capacity (gbps and tbps) backbone telecommunications links and the development of optical transport technologies like SONET that take advantage of these low BERs. In the case of both wireline cables and fiber-optic cables, extremely reliable communications links may be established. Unfortunately, this cannot be said for the radio channel. The next section will examine the characteristics of the air interface.

Radio Wave Propagation and Propagation Models

Before looking at any particular EM propagation models, a general overview of terrestrial EM propagation is warranted. EM waves below approximately 2 MHz tend to travel as ground waves. Launched by vertical antennas, these waves tend to follow the curvature of the earth and lose strength fairly rapidly as they travel away from the antenna. They do not penetrate the ionospheric layers that exist in the upper portions of the earth's atmosphere. Frequencies between approximately 2 and 30 MHz propagate as sky waves. Bouncing off of ionospheric layers, these EM waves may propagate completely around the earth through multiple reflections or "hops" between the ground and the ionosphere. Frequencies above approximately 30 MHz tend to travel in straight lines or "rays" and are therefore limited in their propagation by the curvature of the earth. These frequencies pass right through the earth's ionospheric layers. The daily and seasonal variations that occur in the characteristics of the ionospheric layers give rise to the repeated use of the word *approximately* in the previous explanations.

Other propagation considerations include antenna size and the penetration of structures by EM waves. Antenna size is inversely proportional to frequency. The higher the frequency of operation the smaller the antenna structure can be, which is an important consideration for a mobile device. Also, as frequency increases and wavelength decreases, EM waves have a more difficult time penetrating the walls of physical structures in their path. At frequencies above 20 GHz for example, signals generated within a room will usually be confined within the walls of a room. At even higher frequencies, atmospheric water vapor or oxygen will attenuate the signal as it propagates through the atmosphere. These effects, although appearing detrimental at first, can be used to one's advantage for certain applications. More will be said about this topic later on.

When first-generation AMPS cellular radio was first deployed in the United States, it used frequency bands (in the 800-MHz range) refarmed from the upper channels of the UHF television band. These frequencies provided appropriate propagation conditions, antenna size, and building penetration properties. The PCS bands in the 1900-MHz range and the new AWS bands in the 1710- and 2100-MHz range are also suitable for mobile wireless. These services all use licensed spectrum in the ultrahigh-frequency (UHF) band that has been auctioned off (or will be) by the FCC in various-size pieces to different operators and service providers in different basic and major trading areas. New standards for wireless LANs call for operation in either the unlicensed instrumentation, scientific, and medical (ISM) frequency bands or the new unlicensed national information infrastructure (U-NII) bands. The use of either expensive licensed frequencies or free unlicensed frequencies puts a new spin on how the wireless industry will evolve.

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Wave Propagation Effects at UHF and Above

Since all of the world's mobile wireless systems use the UHF (300–3000 MHz) band, some additional details about propagation above 300 MHz will be given at this time. Note also that the presently used ISM and U-NII bands are located in both the UHF and superhigh-frequency (SHF) bands (3–30 GHz). For signal propagation both indoors and outdoors, three major effects tend to determine the final signal level that is received at the mobile station from the base station and, the reverse case, the signal level received by the base station from the mobile. In theory, by what is known as the reciprocity theorem, the path loss for these two cases should be almost identical.

These three primary propagation effects are reflection, scattering, and diffraction. Reflection occurs for EM waves incident upon some type of large (compared to a wavelength) surface. For a smooth surface the EM wave undergoes a specular reflection, which means that the angle of incidence equals the angle of reflection. How much of the signal power is reflected from a smooth surface or transmitted into it is a complex function of the type of material, the surface roughness, frequency of the incident EM wave, and other variables. In general, the more electrically conductive the surface or the higher the material's relative dielectric constant, , the greater the amount of signal reflection. And, conversely, the lower the value of , the greater the amount of signal transmission into the medium. Scattering occurs when the signal is incident upon a rough surface or obstacles smaller than a wavelength. This case produces what is known as a diffuse reflection (i.e., the signal is scattered in many different random directions simultaneously). Finally, diffraction is a subtle effect that causes EM waves to appear to bend around corners. An EM wave incident upon a sharp corner (e.g., the edge of a building rooftop) causes the generation of a weak point source that can illuminate a shadow or non-LOS (NLOS) area behind the object.

See Figure 8–1 for an example of an outdoor propagation case and Figure 8–2 for an example of an indoor propagation case. As shown by Figure 8–1 several signal paths may (and usually do) exist between the base station antenna and the mobile station. The primary signal tends to follow the line-of-sight (LOS) path while several to many other secondary, tertiary, or higher-order reflections also arrive at the mobile. In addition, diffraction of the base station signal can occur from almost any type of object and therefore any number of diffracted signals might also arrive at the mobile. For this case, all the signals arriving at the number of diffracted signals

outer atmosphere

250 Km

Stratosphere

Troposphere

Earth

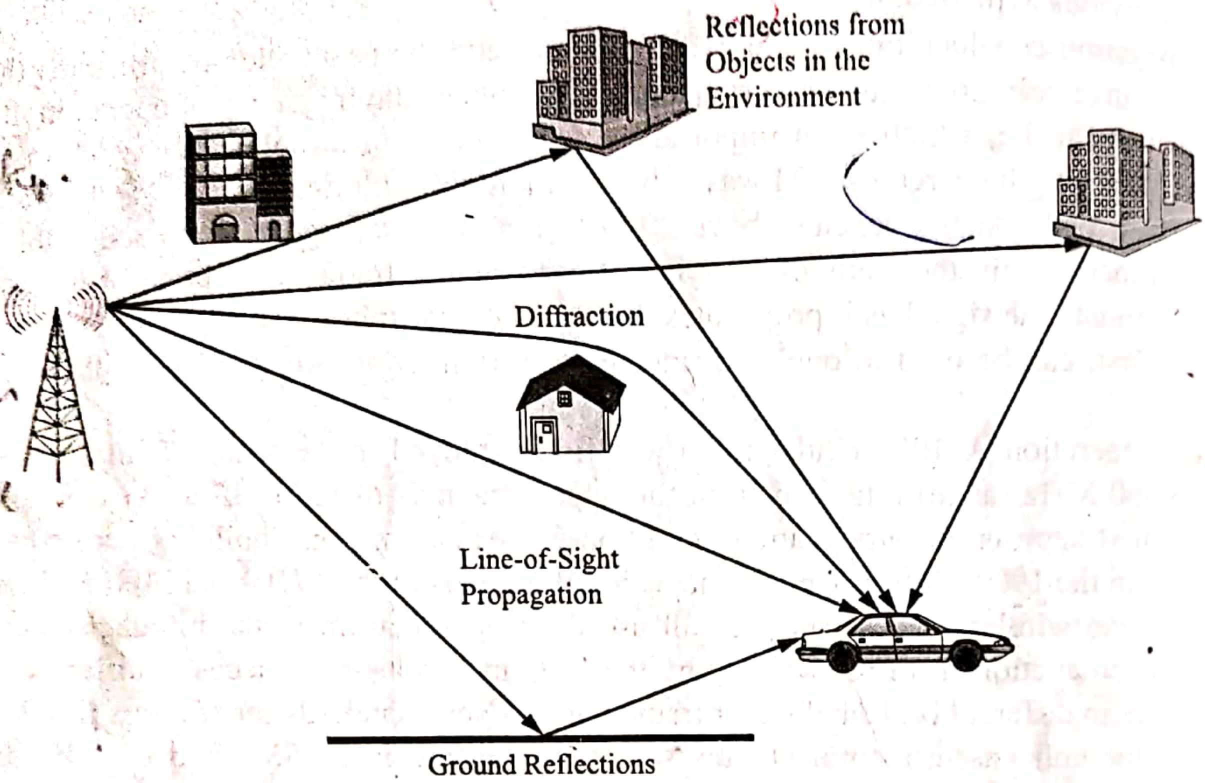

Figure 8–1 Typical outdoor propagation case.

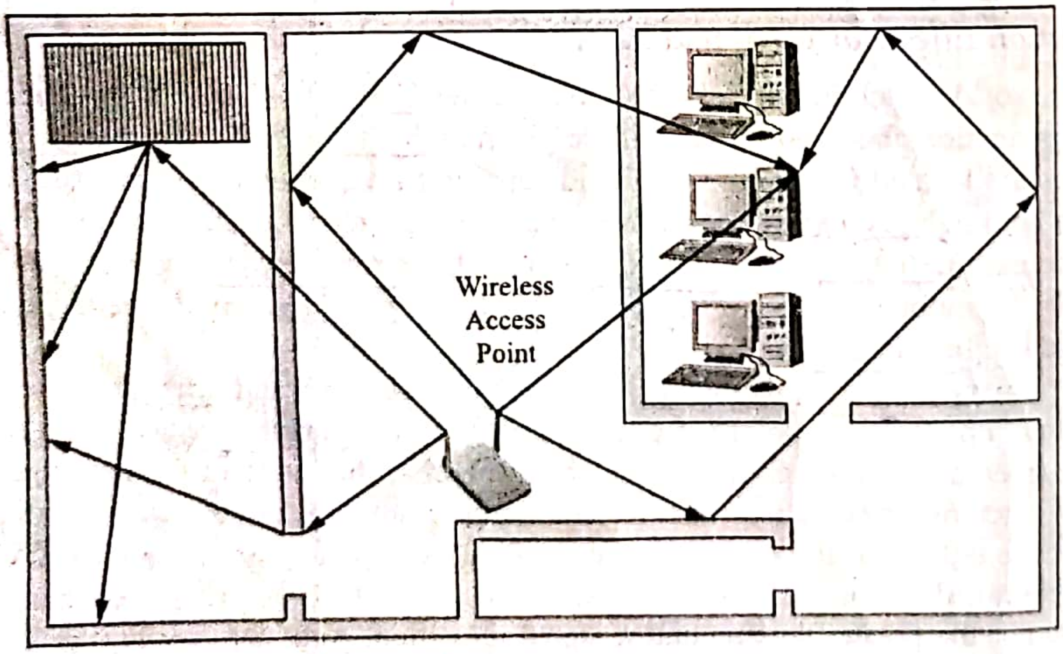

Figure 8–2 Typical indoor propagation case.

mobile add together vectorially (i.e., both amplitude and phase), with the strongest signals tending to create the composite received signal. **Multipath** is the common term used to describe this type of propagation scenario. Also, note that due to the distances involved, there can be a fairly large spread of delays relative to the LOS signal due to the variety of possible paths that the other secondary signals might travel.

Figure 8–2 shows an example of an indoor propagation situation similar to what might be encountered with a wireless LAN access point and a wirelessly enabled laptop. In this case, the signal from the transmitter propagates through the walls between the rooms, experiences numerous reflections off of walls in a corridor and other interior walls, and undergoes diffraction and scattering due to various other obstacles and sharp corners. Again, all the signals arriving at the receiver will add together vectorially to create the composite received signal. For this case, due to the short propagation distances involved, there will be only a small spread of delays between the arriving signals. This important point will be expanded upon shortly. For the case of a cellular call being received within a structure or a particular wireless LAN situation there may be no direct or unobstructed LOS signal. This being the case, the composite received signal is primarily composed of many weaker secondary signals. As the reader may have already concluded, there are a myriad of possible situations and conditions that might arise for both outdoor and indoor propagation cases. Additionally, the effect on received signals for the case of a mobile moving about within a system's coverage area has not been addressed as of yet.

Path Loss Models for Various Coverage Areas

The first **path loss** model to consider is that for free space propagation. It may be shown fairly easily that without any outside influences the propagating signal power of an EM wave decreases by the square of the distance traveled as it spreads out. Therefore, the EM wave undergoes an attenuation of −6 dB every time the distance it travels doubles. The power received from an antenna radiating P_T watts in free space is given by the following equation (known as the Friis equation):

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 \qquad \textbf{8-1}$$

where G_T and G_R are the transmitting and receiving antenna link gains, respectively, λ is the signal wavelength, and d is the distance from the transmitting antenna. A typical technique to simplify the usage of this equation is to rewrite it as:

$$P_R = P_0/d^2 \qquad \textbf{8-2}$$

where P_0 is the received signal strength at a distance of one meter. Once P_0 has been calculated, it is a simple task to determine the received signal strength at other distances. Also important to note here is that in the free space environment the velocity of propagation for an EM wave translates into an approximately 3.3-ns-per-meter time delay. This means that it takes 3300 ns for a signal to travel a distance of 1000 meters in free space. This fact will be called upon later in our further discussions about multipath propagation. At this point, a free space path loss example is appropriate.

Example 8–1

What is the received power in dBm for a signal in free space with a transmitting power of 1 W, frequency of 1900 MHz, and distance from the receiver of 1000 meters if the transmitting antenna and receiving antennas both use dipole antennas with gains of approximately 1.6? What is the path loss in dB?

Solution: First calculate P_0 from Equation 8-1

$$P_0 = (1)(1.6)(1.6)(0.1579)/4\pi(1))^2 = .0004042\ \text{W or } -3.934\ \text{dBm}$$

P_R in dBm = $10 \log \left(\frac{P_R}{1\,\text{mi}}\right.$

$P_t = 10 \log \left(\frac{60 \times 10^{-3}}{10^{-3}} \right)$

$P_{R\ in\ dBm} = 10 \log \left(\frac{P_{R\ in\ W}}{10^{-3}} \right)$

$P_R = P_0/d^2 = (\quad)\ dBm$

$(\quad)\ W$

Then from Equation 8-2,

$$P_R = (P_0/d^2) = (.4042\ \text{mW}/1000^2) = .4042\ \text{nW or } -63.934\ \text{dBm}$$

The path loss in dB is the difference between the transmitted power, P_T, and the received power, P_R. Or, in equation form:

$$Path\ Loss = P_T - P_R \qquad 8\text{-}3$$

For this particular example, the path loss is equal to +30 dBm (–63.934 dBm) or 93.934 dB. Note, 1W = +30 dBm.

Unfortunately, the free space model, though instructive, does not give accurate results when applied to mobile radio environments. As already discussed, typically the transmitted signal reaches the receiver over several different paths. At this time several other models will be discussed in the context of relative cell size and environment (i.e., indoor and outdoor).

12.2 LINE-OF-SIGHT PROPAGATION

In Section 2 of Chapter 8, the Friis equation for line-of-sight radio wave propagation was discussed. This equation may be used to predict radio wave propagation in free space and also for fixed terrestrial line-of-sight systems if the transmitting and receiving antennas are high enough above the ground and there are no obstructions between them. The Friis equation, repeated here for convenience, predicts the power that will be received from a transmitter at a distance, *d*.

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 \qquad \textbf{12-1}$$

In general, if the link is stationary or fixed, there is even more predictability to the relative received signal strength and the reliability of the link. As pointed out previously in Chapter 8, there are many other propagation effects that can come into play and affect the transmission link. For terrestrial systems, some of these factors include atmospheric attenuation, precipitation, shadowing, and reflected and scattered signal propagation paths. For satellite systems, one adds the effects of transionospheric propagation (i.e., the Faraday effect), signal frequency shift due to the Doppler effect, and signal blocking to the list. The net result in both cases is the possibility of reduced RSS and severe signal-strength fades.

Design of these types of transmission links is usually performed by using software design tools that are optimized for the particular application. For terrestrial links, propagation models based on the line-of-sight Friis equation are combined with terrain data available from geographic information systems (GIS) to provide detailed analysis of point-to-point and point-to-multipoint systems. These sophisticated software programs incorporate transmission component and antenna characteristics, frequency of operation, rainfall rate predictions, the curvature of the earth, clutter height and type, and Fresnel zone and path obstruction diffraction effects. These and other factors are used to design and predict link reliability with a fairly high degree of accuracy. Other design software features usually include signal interference analysis, colorized signal-strength contour maps, diversity schemes, and the ability to generate sophisticated reports of the transmission network, its characteristics, and an inventory of the digital microwave network equipment.

The mathematical prediction of the received signal level from a geosynchronous satellite system is fairly straightforward since the signal propagation path approximates a fixed line-of-sight, obstruction-free link. To deal with the various propagation effects that tend to degrade the received power, a link margin is typically assumed. The link margin is usually specified in dBs and increases with increasing frequency of operation. For these types of calculations one may rearrange and evaluate the Friis equation using dB as shown here:

$$P_R(\text{dBm}) = P_T(\text{dBm}) + G_T(\text{dB}) + G_R(\text{dB}) - 20\log\left(\frac{4\pi d}{\lambda}\right) \qquad \textbf{12-2}$$

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Example 12–1

If the nominal transmitter output power is 120 watts for a DIRECTV DBS and the transmitting antenna gain is 34 dB, determine the received signal power if the eighteen-inch receiving dish has a nominal gain of 33 dB. Assume that the operating frequency is 12.45 GHz and the receiving antenna is directly below the satellite.

Solution: First calculate the wavelength, λ, in meters. Since,

$$\lambda = \frac{300}{f\ (\text{MHz})}, \qquad \lambda = \frac{300}{12,450} = 0.0241\ \text{m}$$

Next, convert 120 watts to dBm; this can be done by using the formula,

$$P_T\,(\text{dBm}) = 10 \log\left(\frac{120\text{W}}{1\text{mW}}\right) = 50.8\ \text{dBm}$$

Now, using Equation 12-2 one calculates:

$$P_R = 50.8\text{dBm} + 34\text{dB} + 33\text{dB} - 20\log\left(\frac{4\pi \times 35,786,000}{0.0241}\right) = 117.8$$

50.8 + 83.6.

$$P_R = 117.8\text{dBm} - 205.4\text{dB} =$$

$$P_R = -87.6\text{dBm}$$

Thus the received signal level is approximately –87.6 dBm. With a receiver noise temperature of about 75°K, combined with the forward error correction coding scheme used by the transmitter, this is a sufficient signal level to provide fairly good-quality video reception.

Digital M... ...censed bands or the new unlicensed

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user often has the ability to mix or partition the type of transmitted data signals. Today's equipment commonly uses QPSK, 8-PSK, 16-QAM, 32-QAM, or higher-order QAM modulation techniques and allows transmission of a mix of nxDSn (i.e., various combinations of multiple DS1s or DS3s or a mix of both) and Ethernet at various bit rates. Typical transmitter output powers are in the +16 to +25 dBm range with receiver sensitivities in the –70 to –90 dBm range depending upon the frequency of operation, the type of modulation, transmitted signal bandwidth, and the final mix of data transmission streams.

Example 12–2

A digital microwave link is set up to transmit 24 DS1s using 16-QAM with a 20-MHz bandwidth at 38 GHz. Both the transmitting and receiving antennas have diameters of 30 cm and a nominal gain of 38.5 dB. If the transmitter output power is +16 dBm and the receiver sensitivity is –74 dBm for a bit error rate of 10^{-7}, determine the maximum system range assuming unobstructed LOS propagation and a 15-dB link margin.

Solution: Using Equation 12-2, one may calculate:

$$P_R(\text{dBm}) = +16\text{dBm} + 38.5\text{dB} + 38.5\text{dBm} - 20\log\left(\frac{4\pi d}{\lambda}\right)$$

With a link margin of 15 dB, the received signal power must be at least –74 dBm +15 dB = –59 dBm for perfect conditions. Therefore,

$$-59\text{dBm} = 93\text{dBm} - 20\log\left(\frac{4\pi d}{\lambda}\right)$$

The wavelength of a 38-GHz signal is given by,

$$\lambda = \frac{300}{38000} = 0.00789\text{ m}$$

And substitution into the prior expression yields $d = 25.0$ km

Therefore, the maximum predicted useful range possible for this digital microwave link is approximately 25 km using this overly simplified mathematical model.

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