Communications & Tracking Basics

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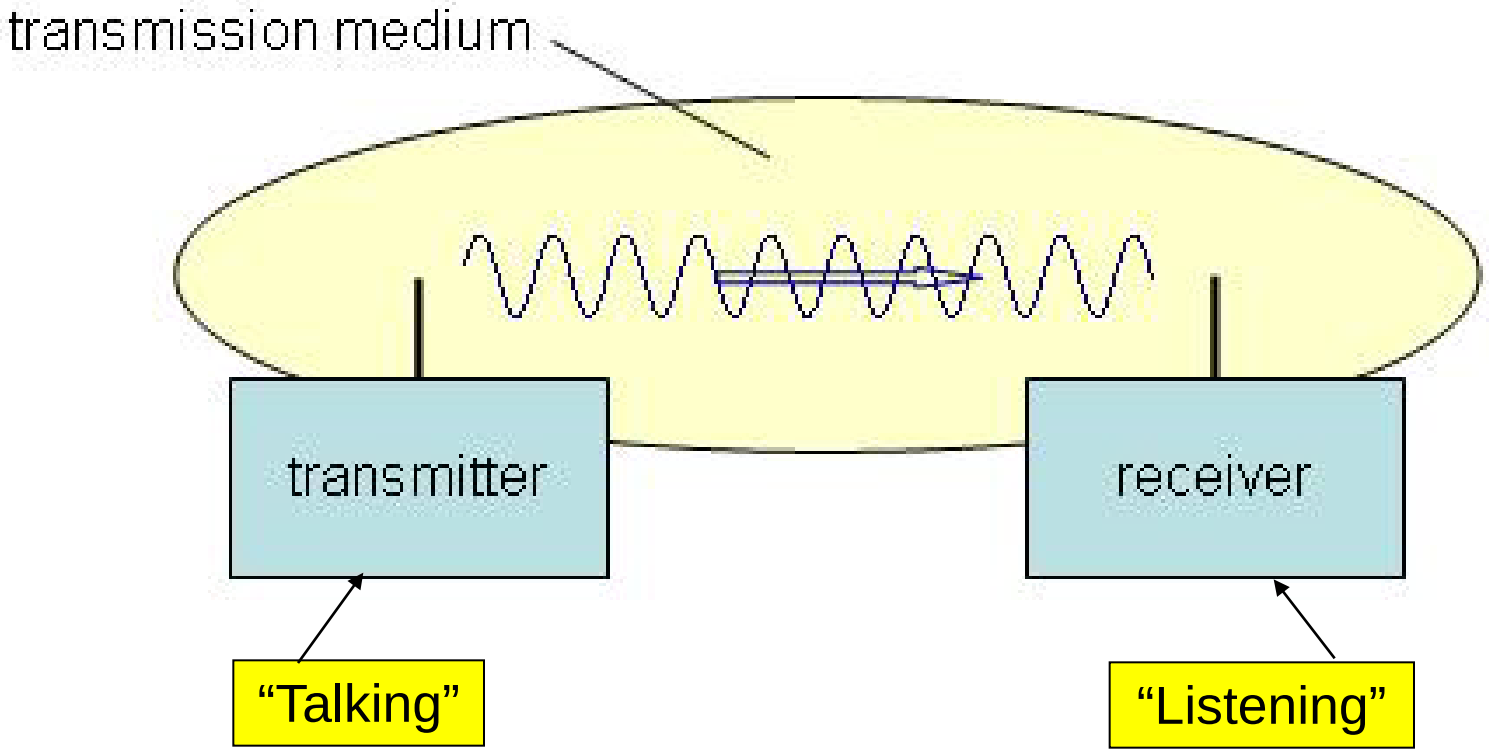
Overview

- **Communications Systems – How they work**
  - General Principles
  - Primary Wireless Systems
  - Alternate Communications Path & Secondary Systems
- **Tracking Systems – How they work**
  - Zone-Based
  - RSSI-based systems

A Communications Link



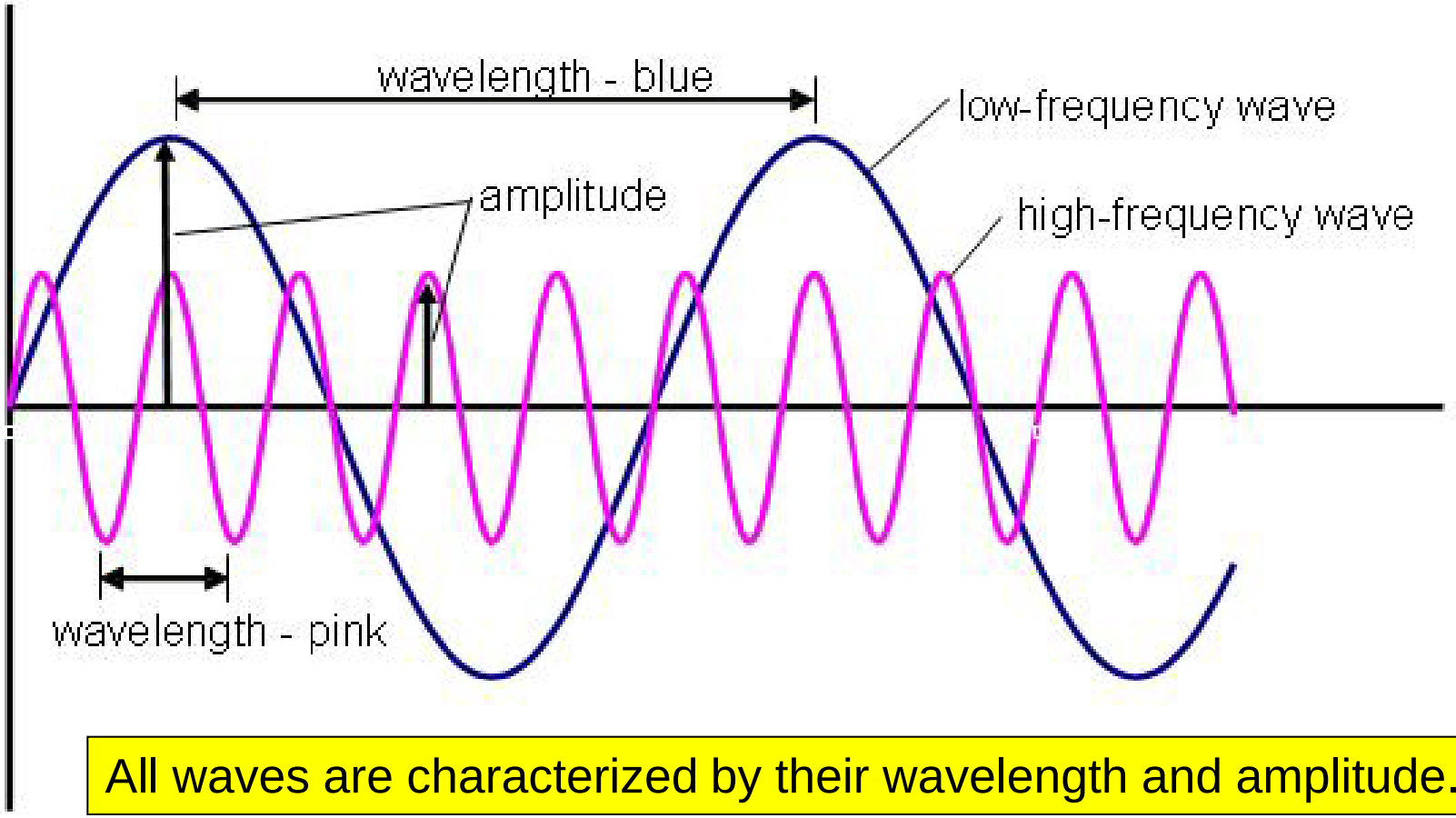
Communications Link Characteristics

- **Amount of power available for communicating across a link is determined by:**
  - **Transmitter Power**
  - **Receiver Sensitivity**
  - **Noise & Other Impairments**
- **The transmitted power is continuously “lost” as the energy travels through the transmission medium.**

Role of EM Energy

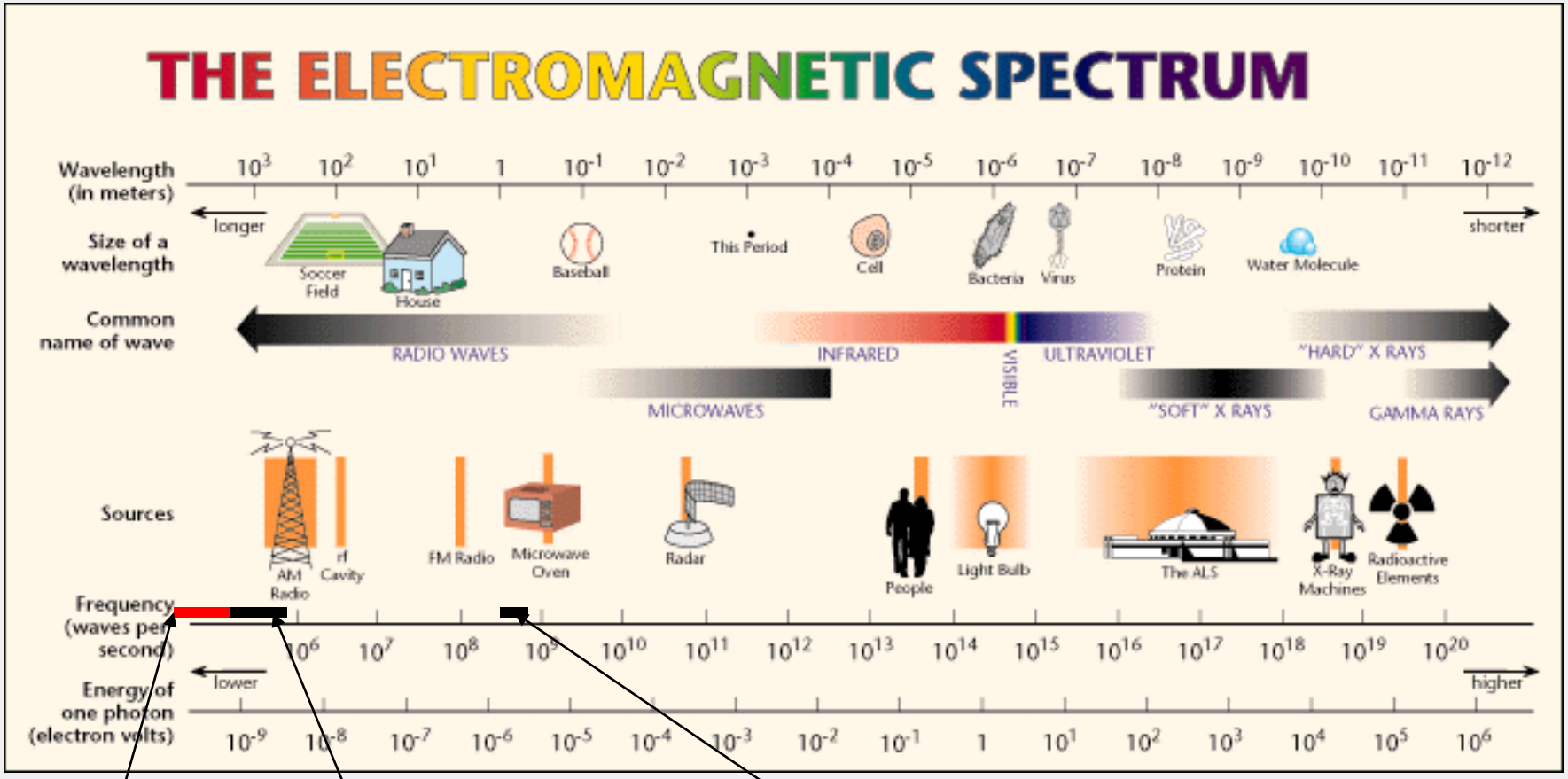
- **All modern communications and tracking (CT) systems depend upon the transmission and reception of energy.**
- **The energy being transferred is referred to as *electromagnetic energy (EM).***
- **Electromagnetic energy is everywhere in the environment and includes radio waves, light energy, and x-rays.**
- **Electromagnetic energy can be visualized as a traveling wave.**

Role of EM Energy



All waves are characterized by their wavelength and amplitude.

Electromagnetic Spectrum



TTE (ULF/ELF/ LF)

MF “Parasitic Propagation”

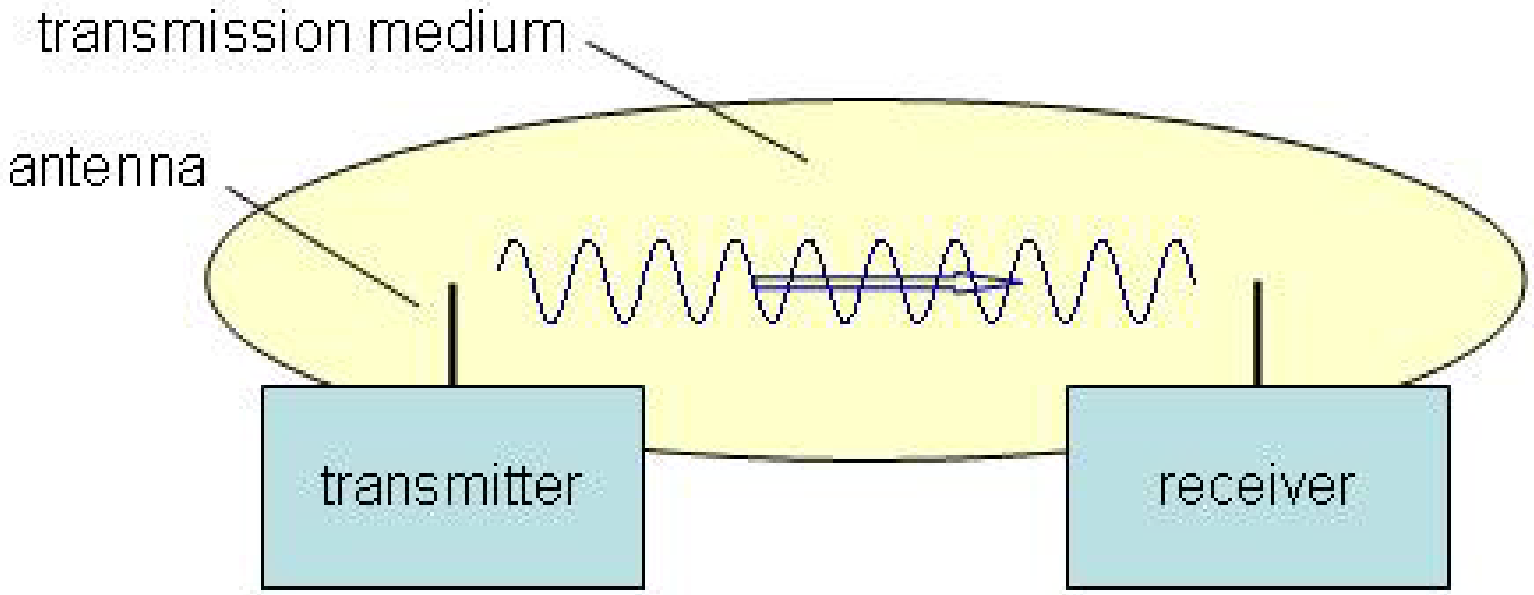
VHF/UHF Mine Entry Waveguide Propagation

Role of EM Energy

- **Wavelengths are chosen to be suitable for “propagating” through the transmission medium.**

Wavelengths for Underground Applications		
System Type	**Transmission Medium**	**Wavelength**
Conventional Two Way Radio	"Free Space"	0.2 to 30 ft
Leaky Feeder	Mine Entry	2 to 7ft
Node based Systems	Mine Entry	0.2 to 2 ft
Medium Frequency	Along metallic structures	2000 to 3200 ft
Through The Earth	Directly through the ground or coal	100,000 ft to 2000 miles

A Wireless Communications Link



The antenna “couples” the energy from the transmitter to the transmission medium or vice versa for the receiver.

Transceivers & Antennas

- **A device that both transmits and receives wirelessly is called a radio transceiver.**
- **Transmitter & Receiver Antennas are an important part of the system.**
  - Long wavelengths (low frequencies) require BIG antennas to effectively couple energy.
  - Short wavelengths (high frequencies) require small antennas (Short wavelengths are commonly used for mobile wireless communications).

Wearable Devices

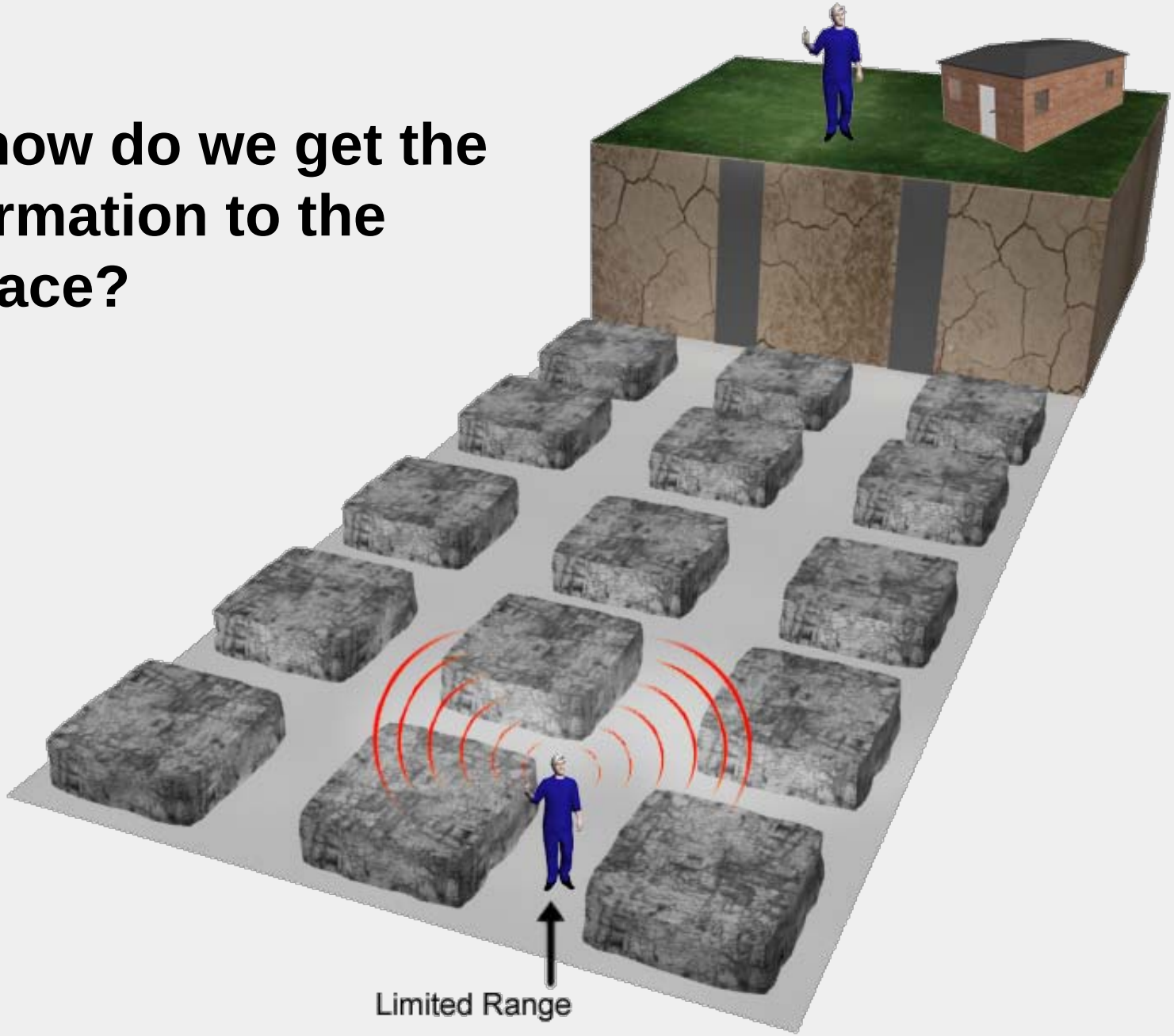
Wearable Devices ⇨ **Conventional Radio Frequencies (VHF – SHF)**

- Conventional two-way radio frequencies (high frequencies) permit the use of antennas and electronics that are small enough to be worn all day by a miner.

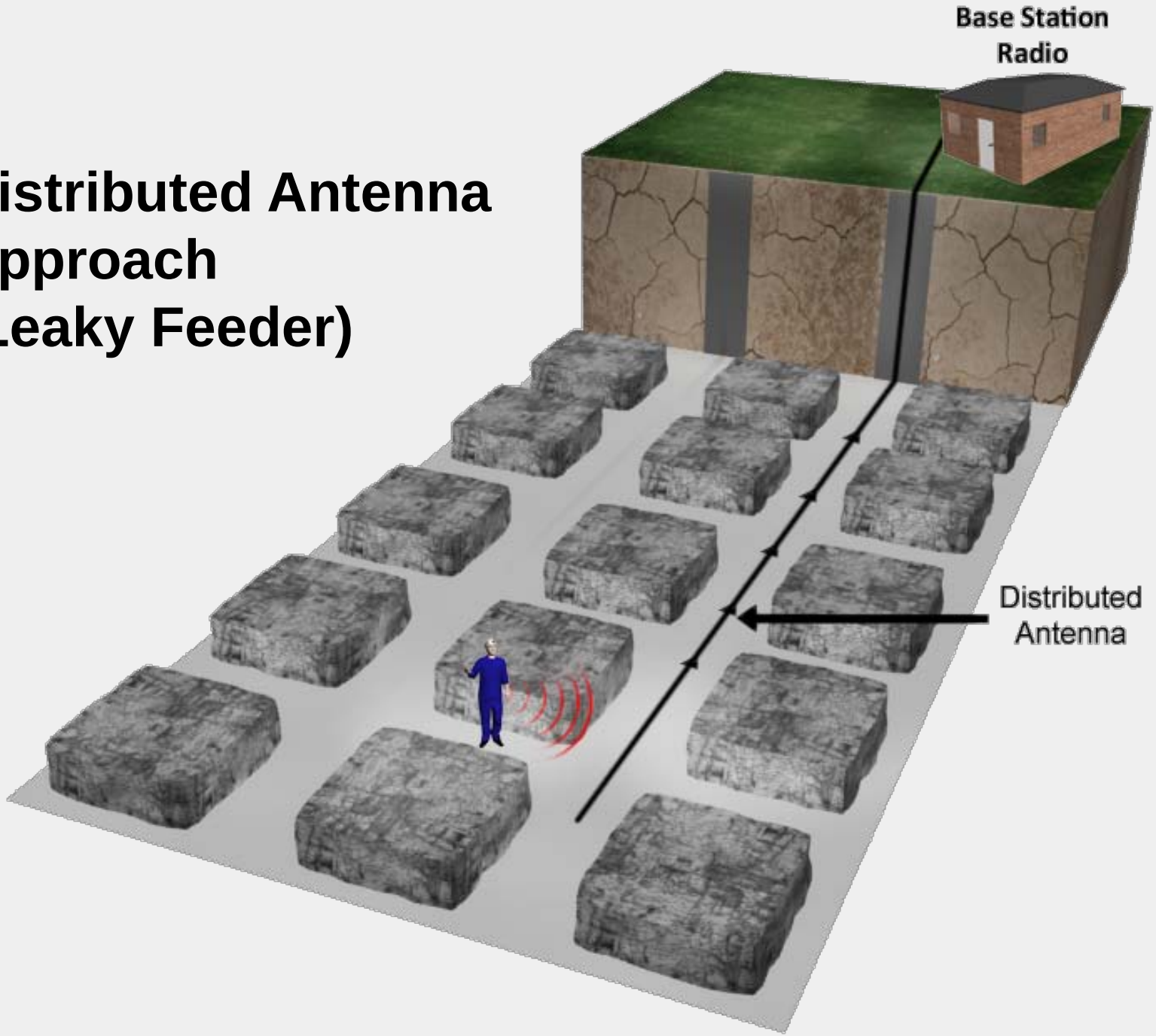
Conventional Radio Frequencies ⇨ **In-mine Infrastructure**

- Analysis and test data results show that radio range using conventional radio frequencies is limited.

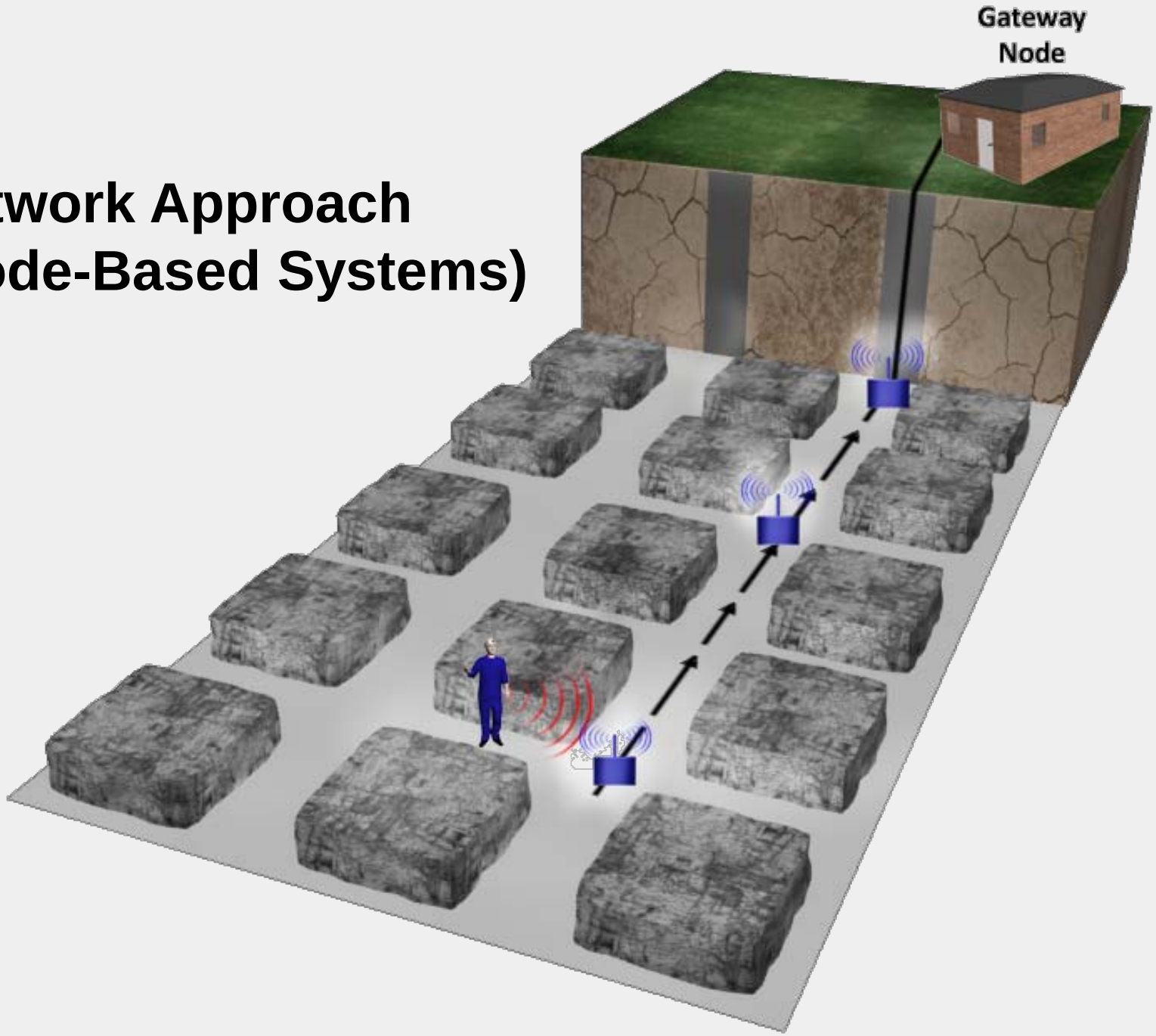
So how do we get the information to the surface?



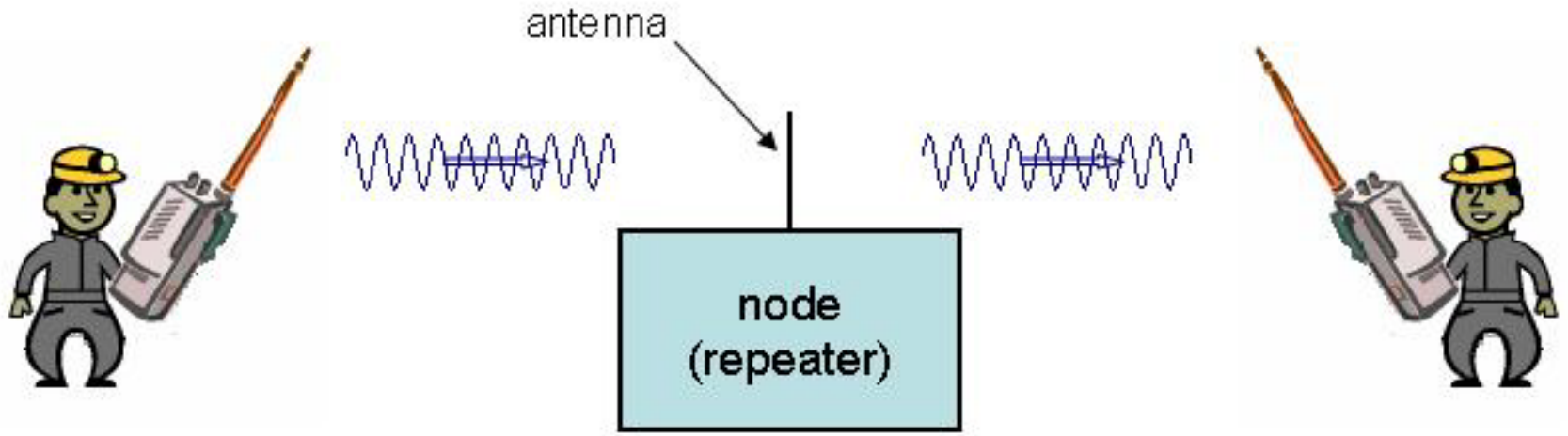
Distributed Antenna Approach (Leaky Feeder)



Network Approach (Node-Based Systems)



Networks

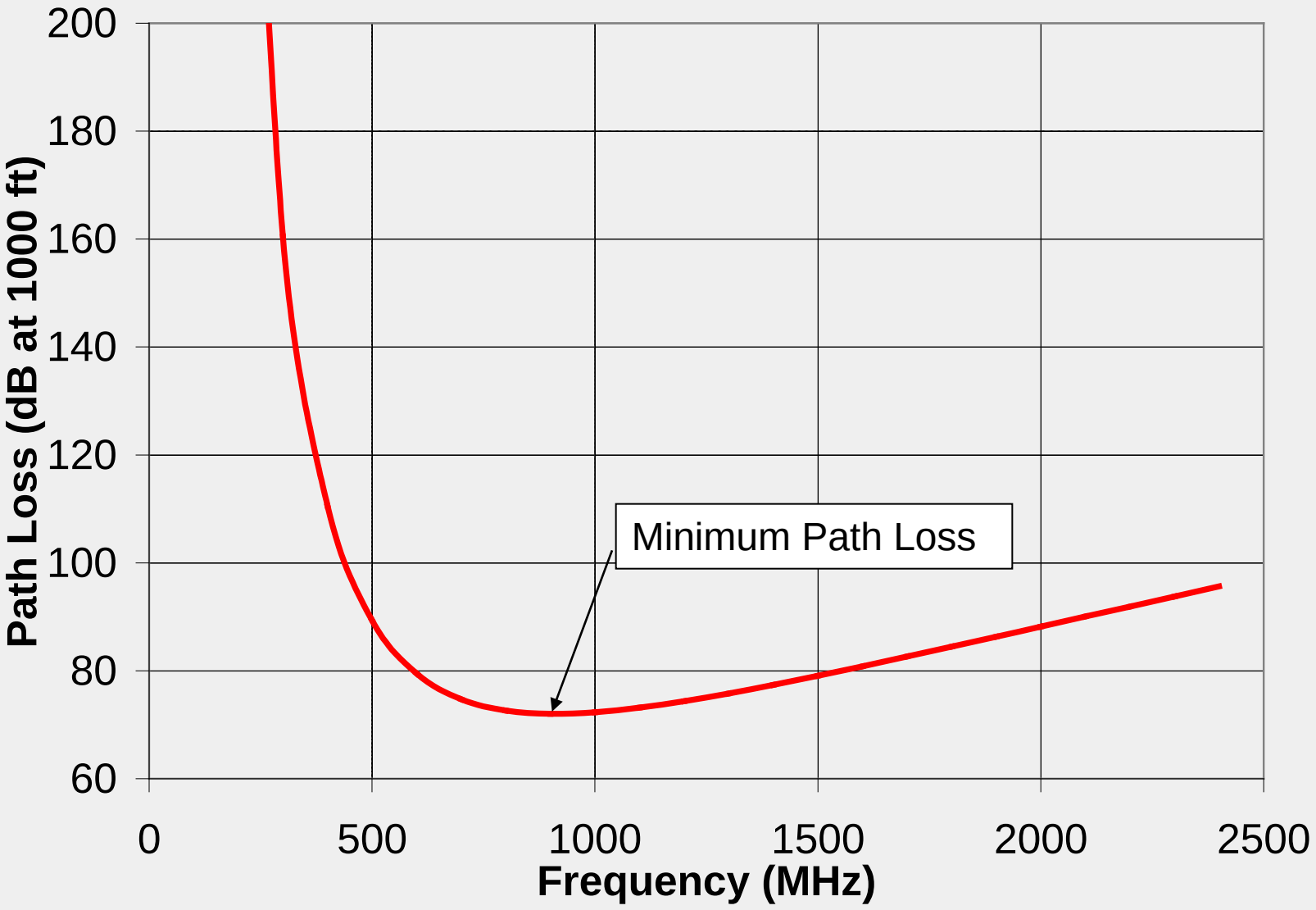


An example of a very simple network

Primary Communications Signal Propagation

- **The radio signals in this part of the spectrum travel or “propagate” along the mine entry.**
- **The wavelength (frequency) that works best has been shown to be dependant on the size of the entry.**
- **For typical entry sizes, the “minimum path loss” is generally between 700 and 1100 MHz.**
- **Smaller openings favor higher frequencies (shorter wave lengths).**

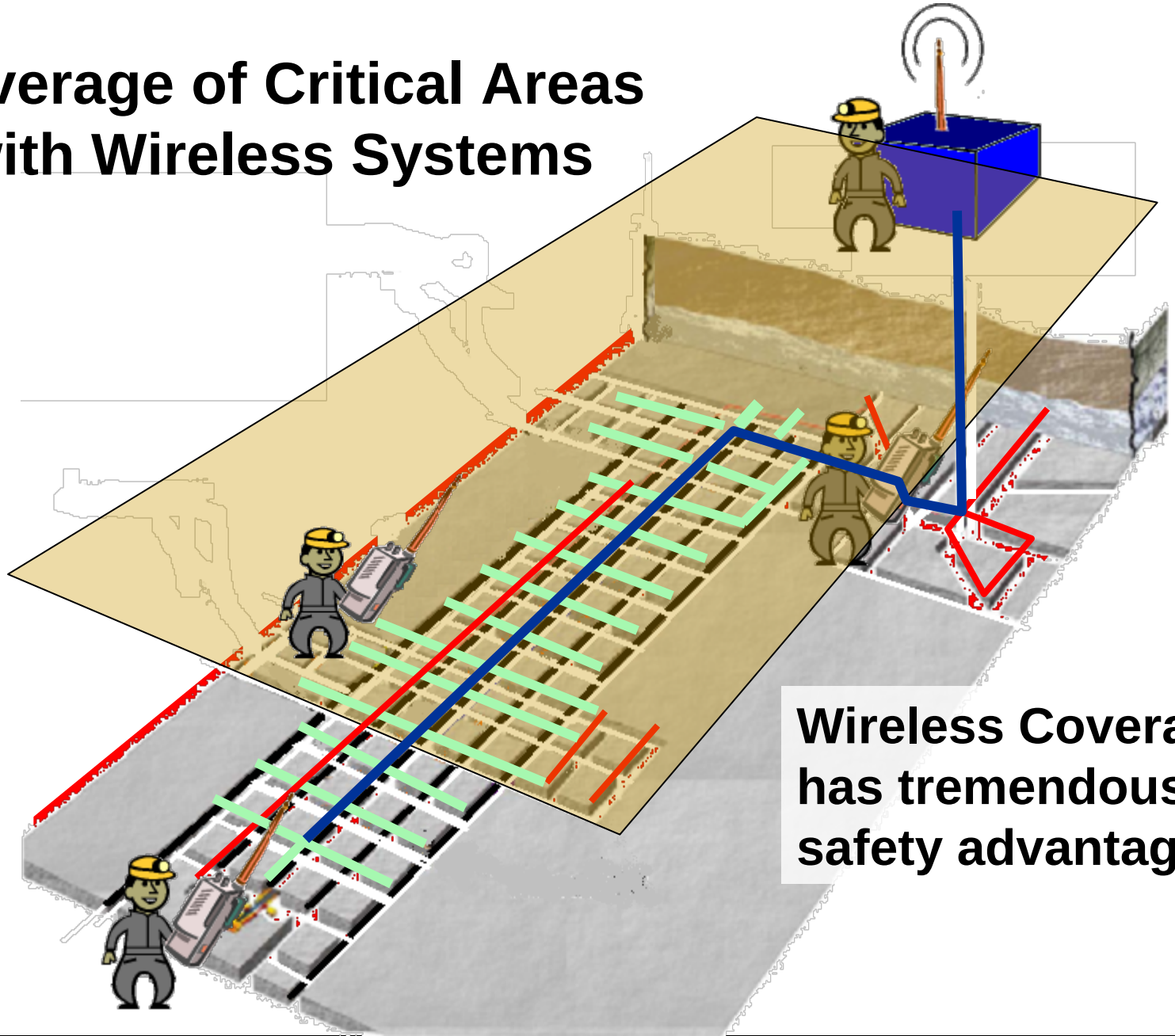
Path Loss versus Wavelength



Primary Communications Systems

- **Leaky feeder and network (node) based systems**
  - Operate in the conventional two-way radio bands
  - Allow the miner to have small devices with long battery life
  - Have sufficient throughput for general, as well as emergency, operations
- **Each approach has advantages, limitations, and inherent vulnerabilities**

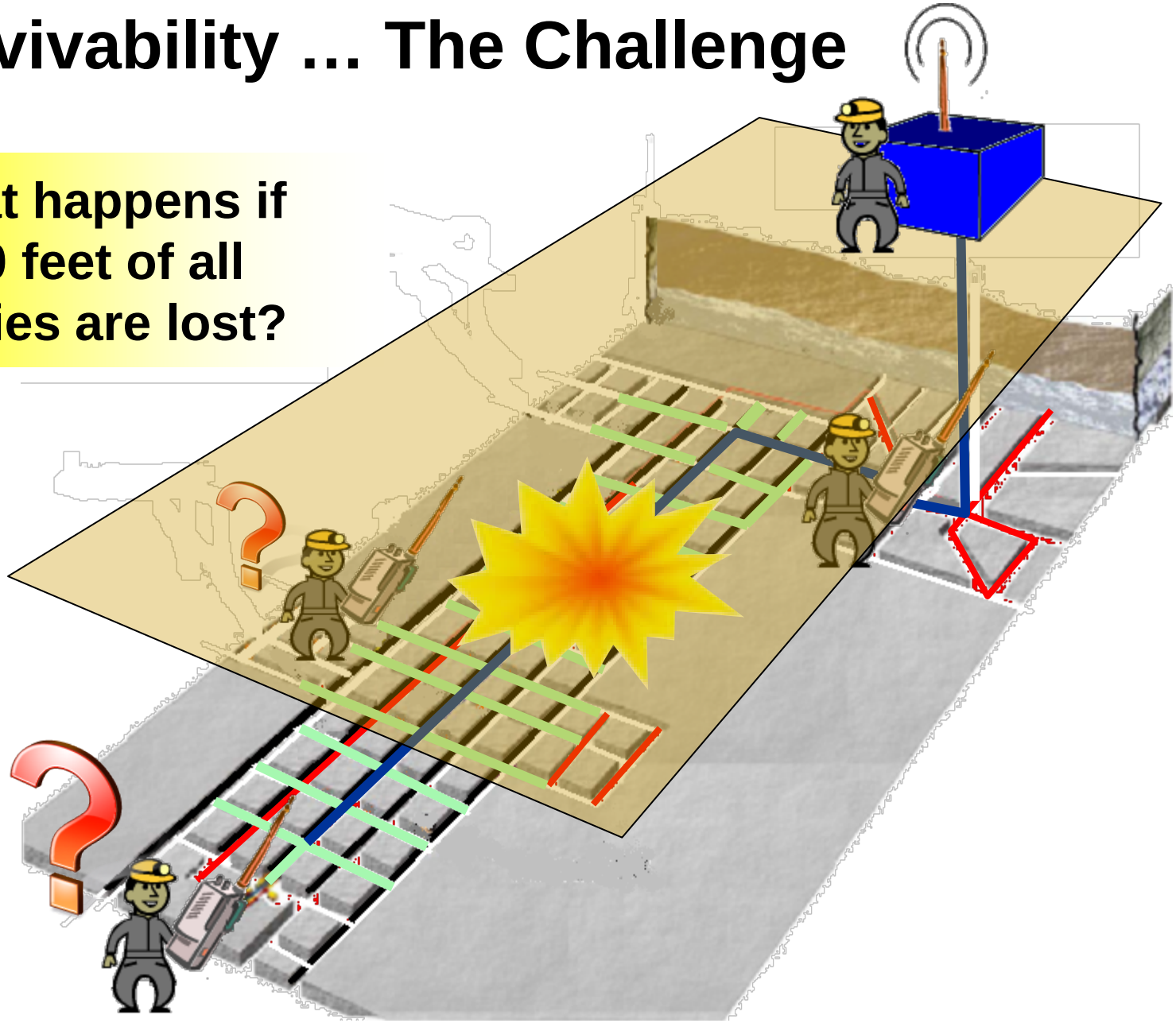
Coverage of Critical Areas with Wireless Systems



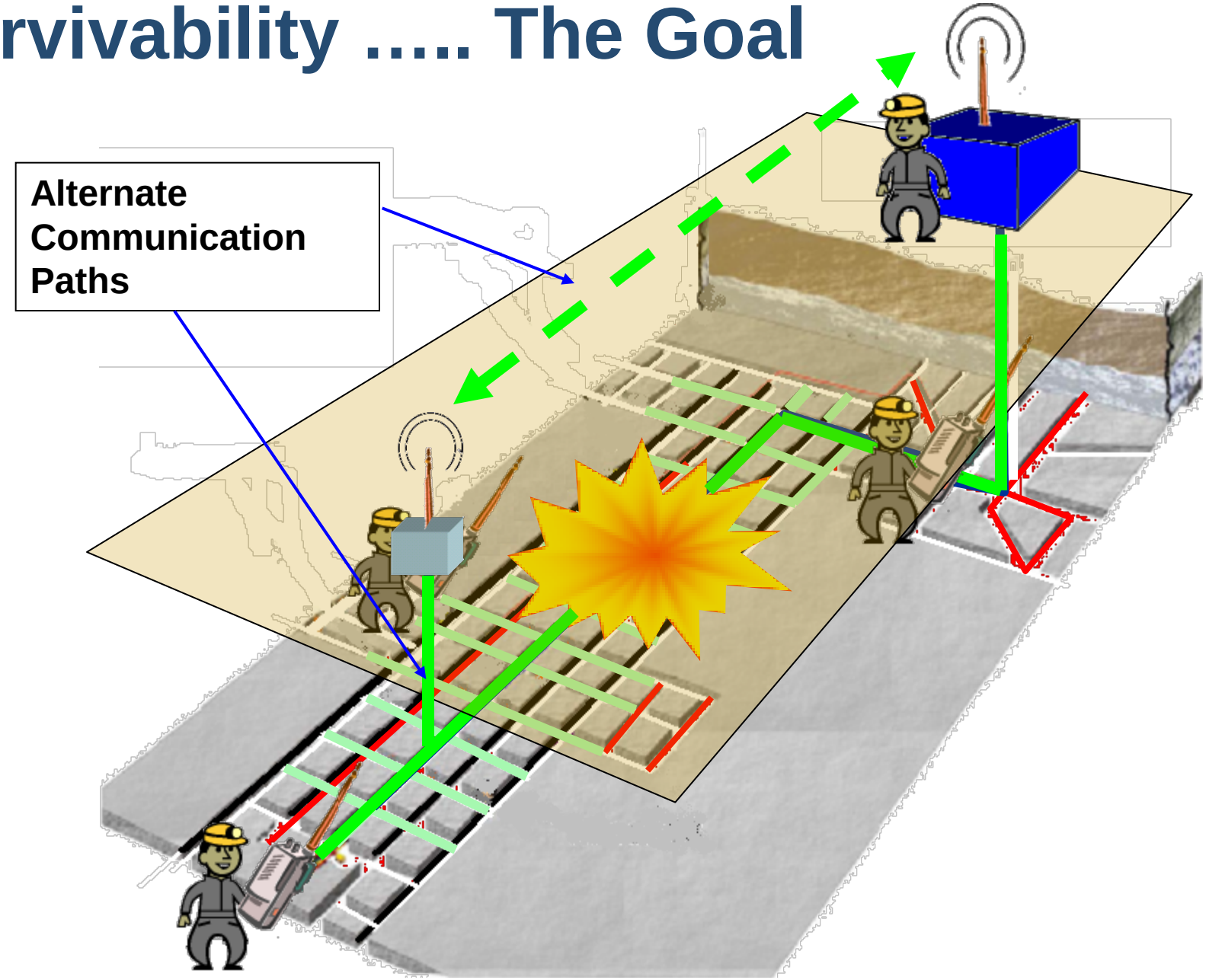
Wireless Coverage has tremendous safety advantages

Survivability … The Challenge

What happens if 2000 feet of all entries are lost?



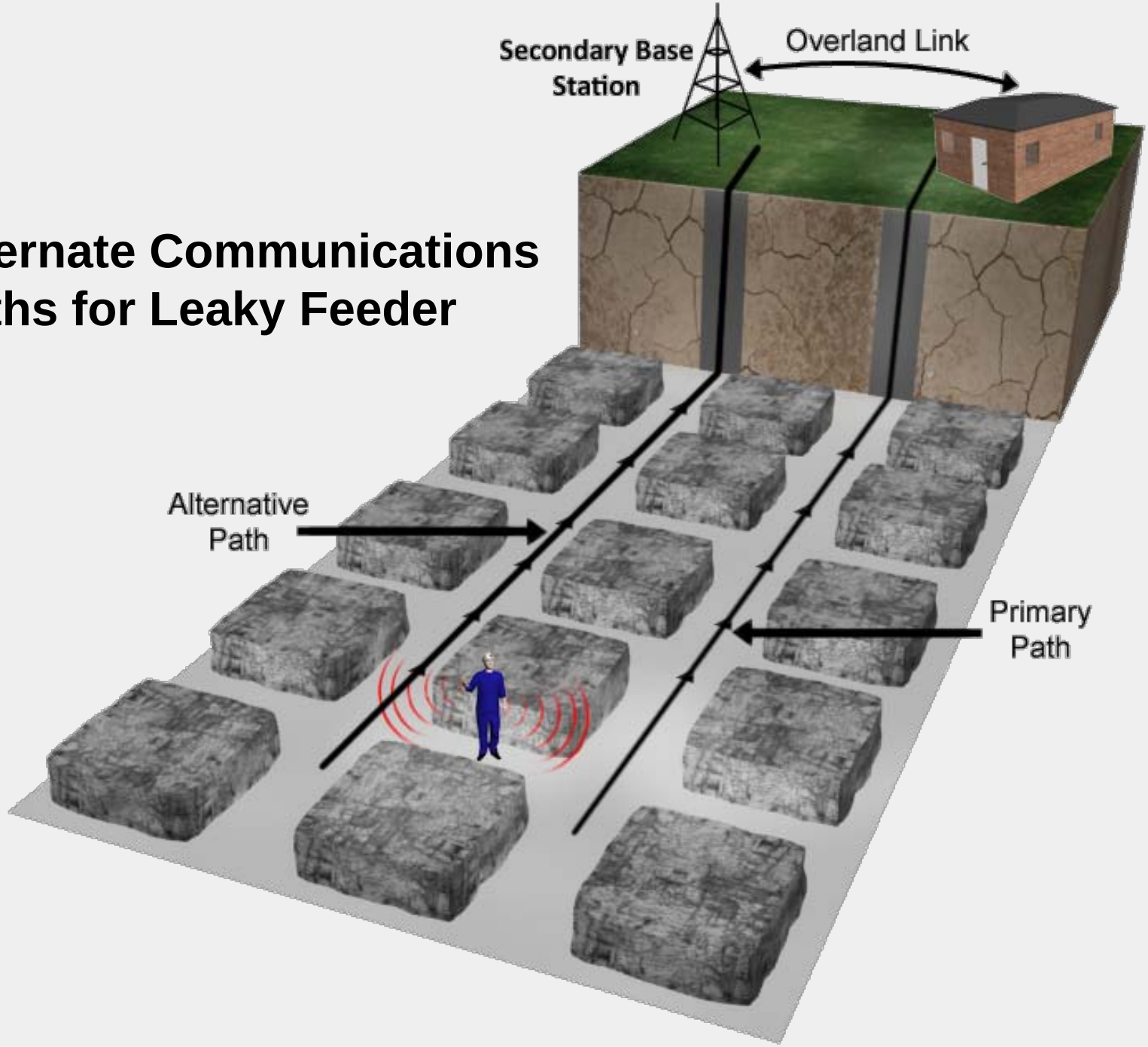
Survivability ….. The Goal



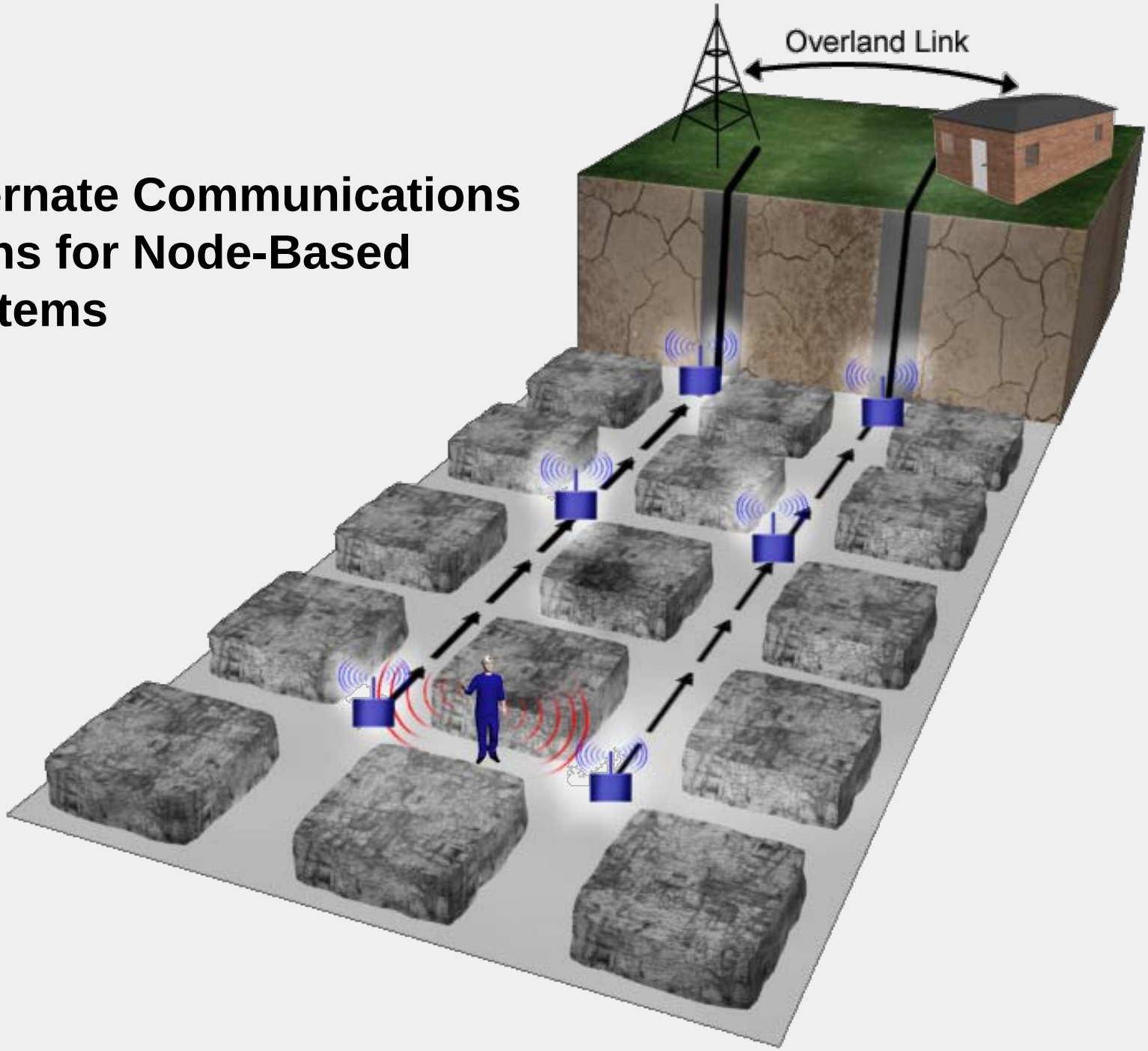
Survivability: The Approach

- **The principal challenge for post-accident operation is survivability.**
- **Lessons learned:**
  - No practical way to harden primary communications infrastructure to survive any conceivable event
  - Survivability is most practically achieved through alternate communications paths
- **Survivability has as much to do with the mine-specific design and installation as it does the technology.**

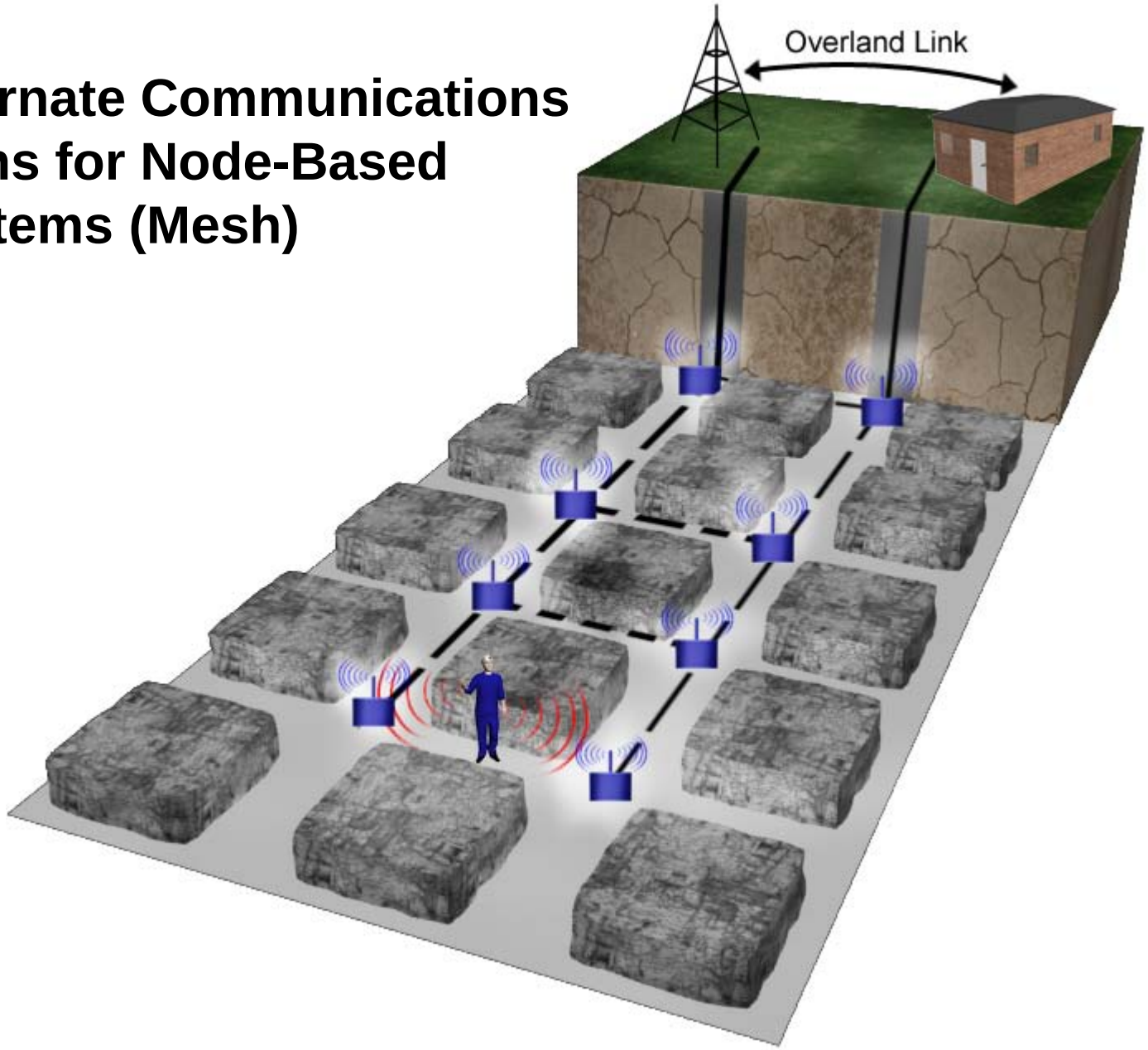
Alternate Communications Paths for Leaky Feeder



Alternate Communications Paths for Node-Based Systems



Alternate Communications Paths for Node-Based Systems (Mesh)



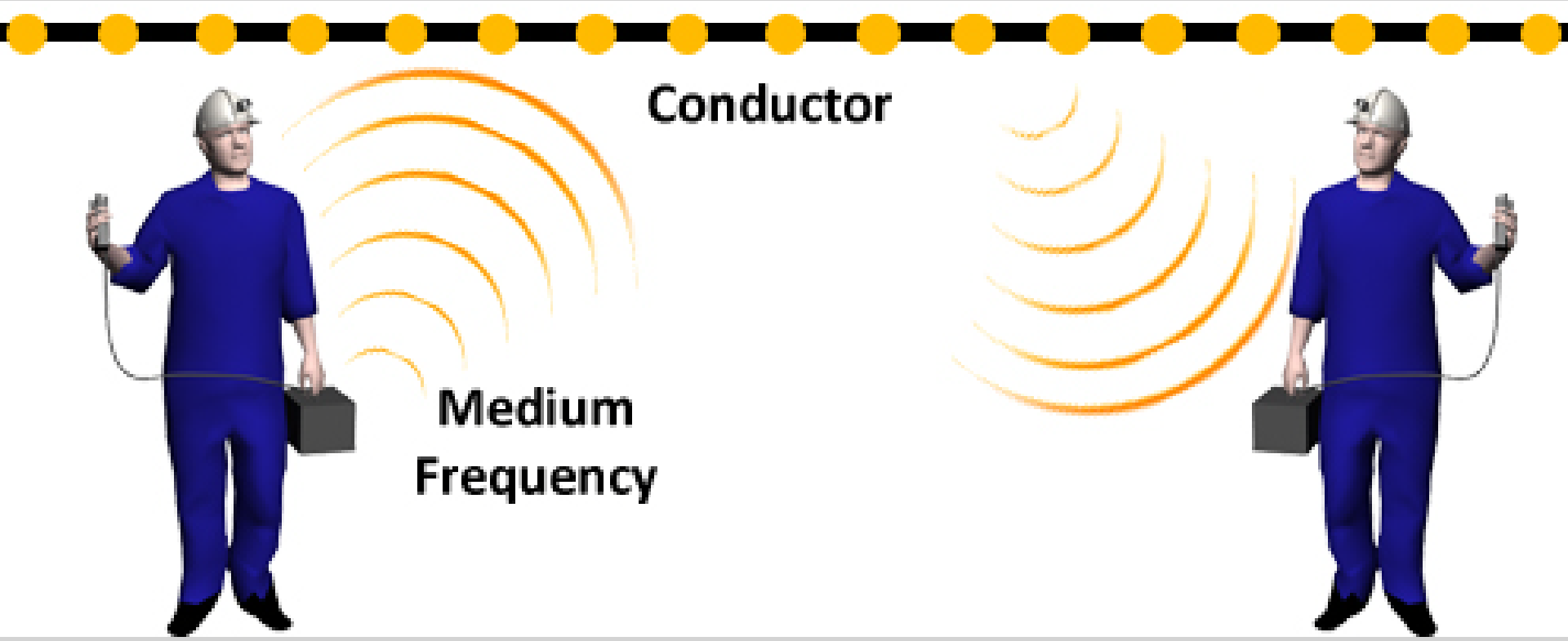
Alternate Communications Paths

- **Alternate communications paths provide system redundancy.**
- **Ideally, the alternate communications path is “truly diverse.”**
- **Independent failure mechanisms**

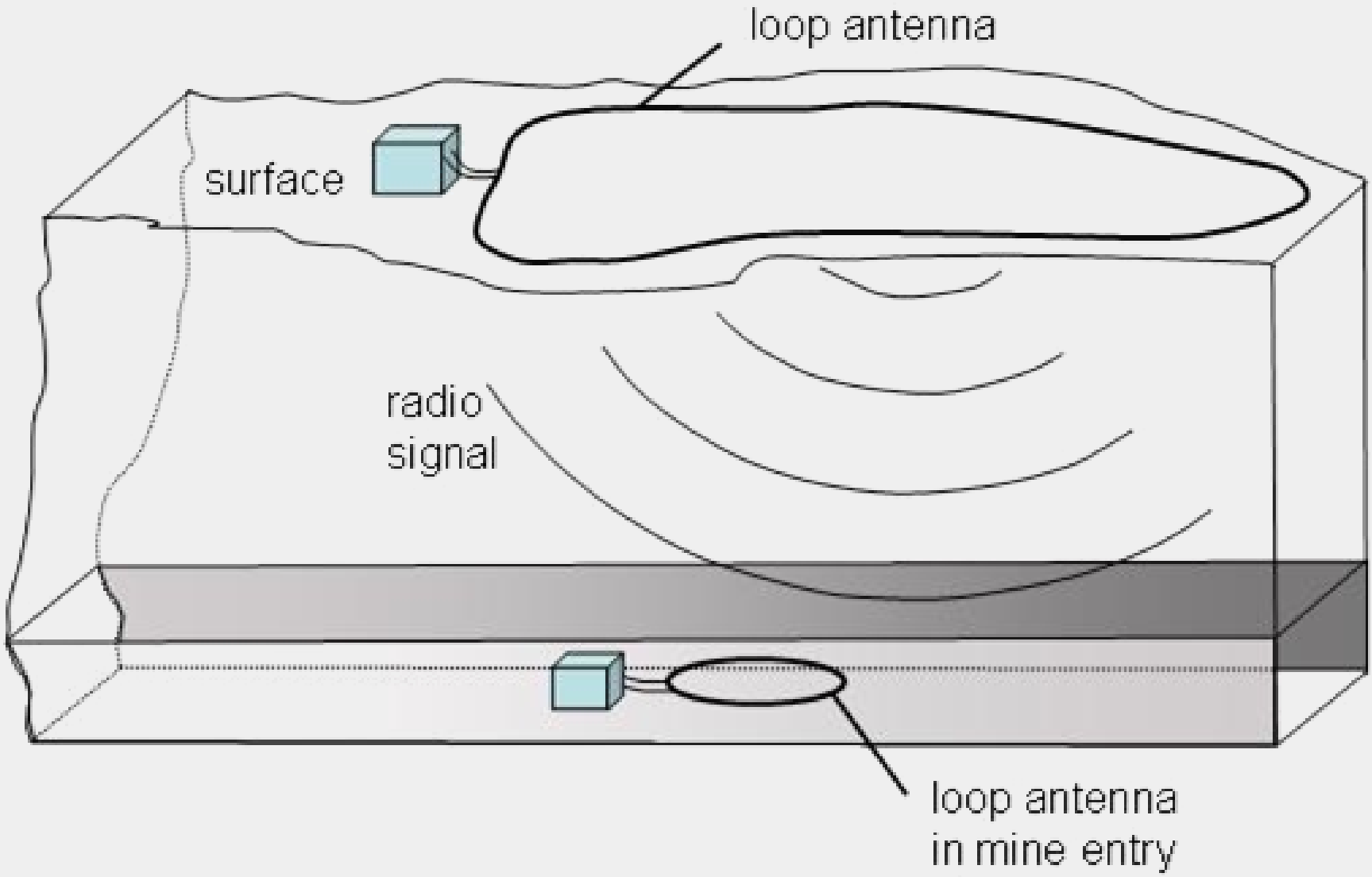
Secondary Systems

- **Medium Frequency Systems and Through-the-Earth Systems are viable secondary systems that can provide alternate communications paths out of the mine.**
- **Secondary System**
  - Operates in non-conventional frequency bands
  - Uses large antennas that are best suited for fixed locations or portable (“luggable”) applications
  - Do not have sufficient throughput for general operations

Medium Frequency Communications



Through-the-Earth (TTE) Communications



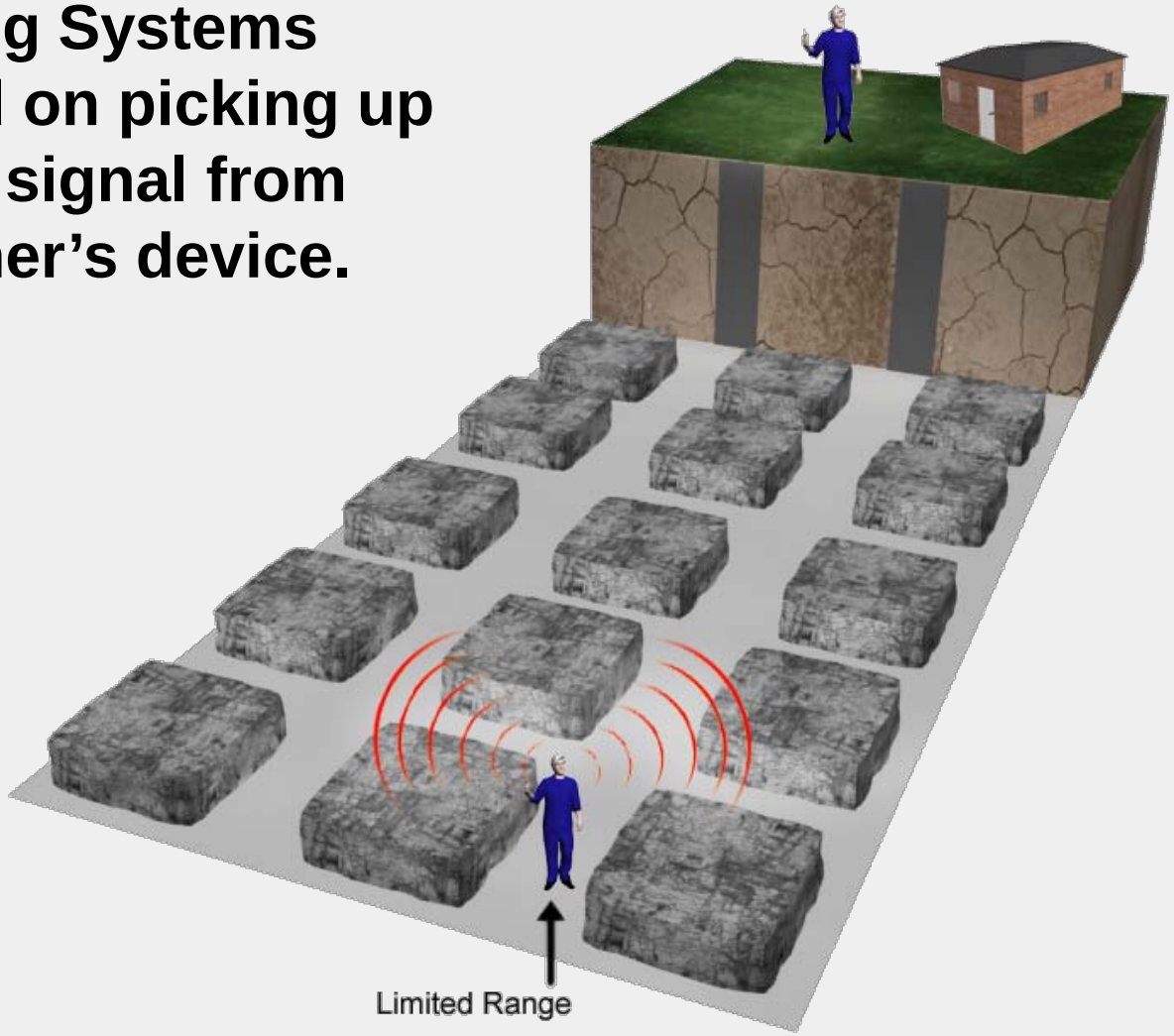
Electronic Tracking Systems

Systems that are anticipated within the MINER Act timeframe are radio-based systems

- Zone-based systems are usually based on RFID (Radio Frequency Identification Device) tags and RFID readers.
- RSSI (Received Signal Strength Indicator)-based systems generally use the same nodes as those for node-based communications.

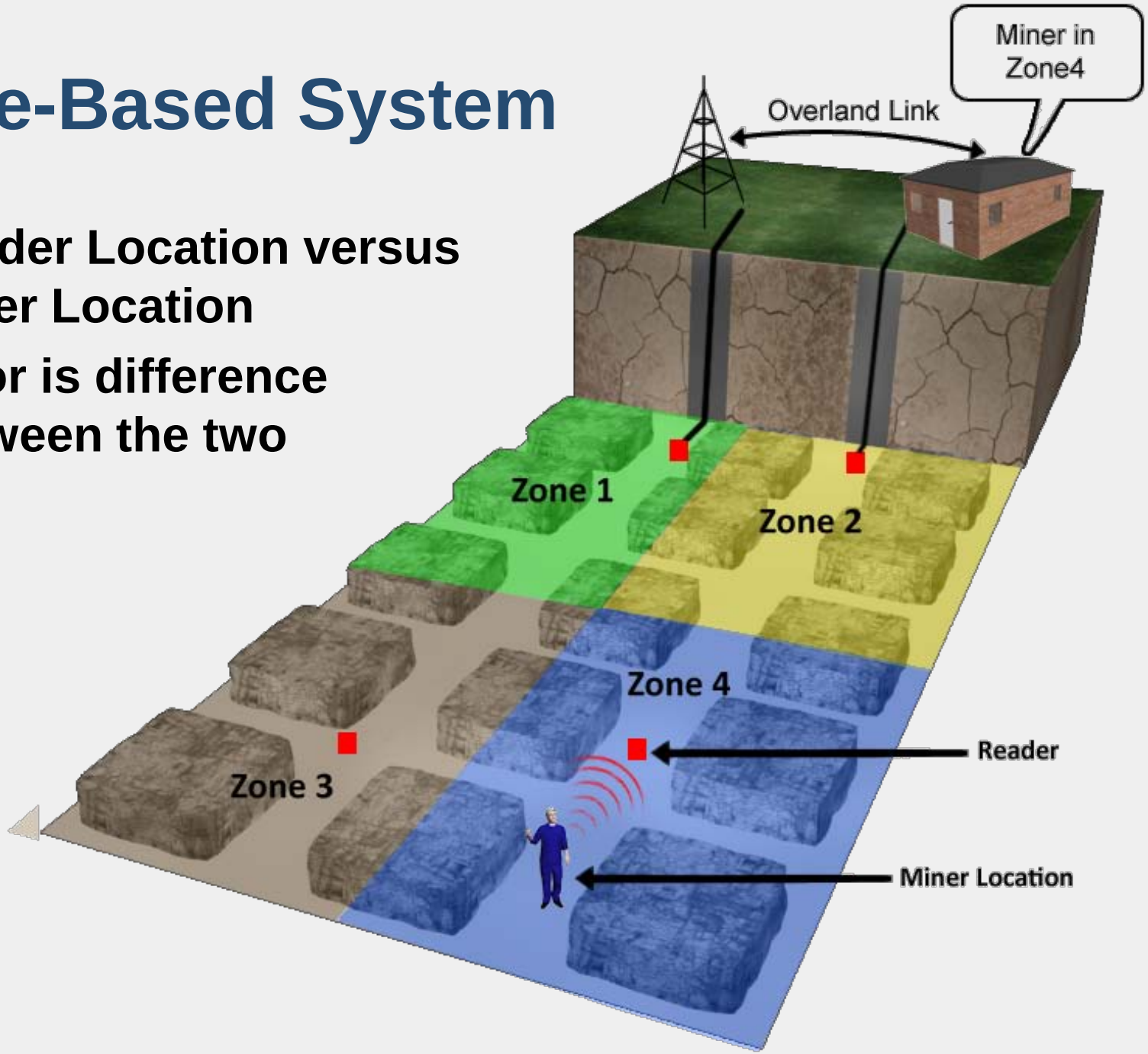
Radio-Based Tracking Systems

Tracking Systems depend on picking up a radio signal from the miner's device.



Zone-Based System

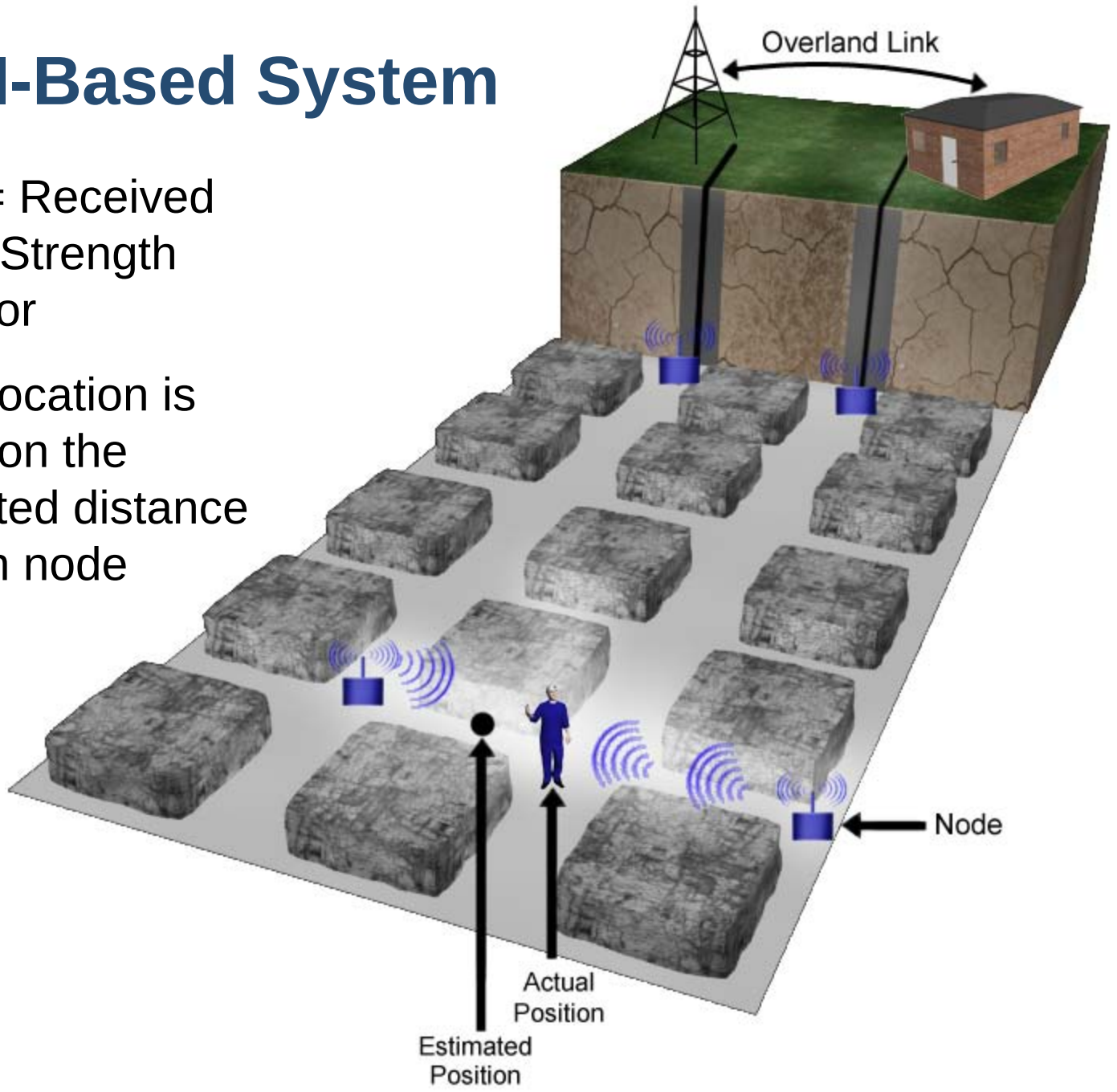
- **Reader Location versus Miner Location**
- **Error is difference between the two**



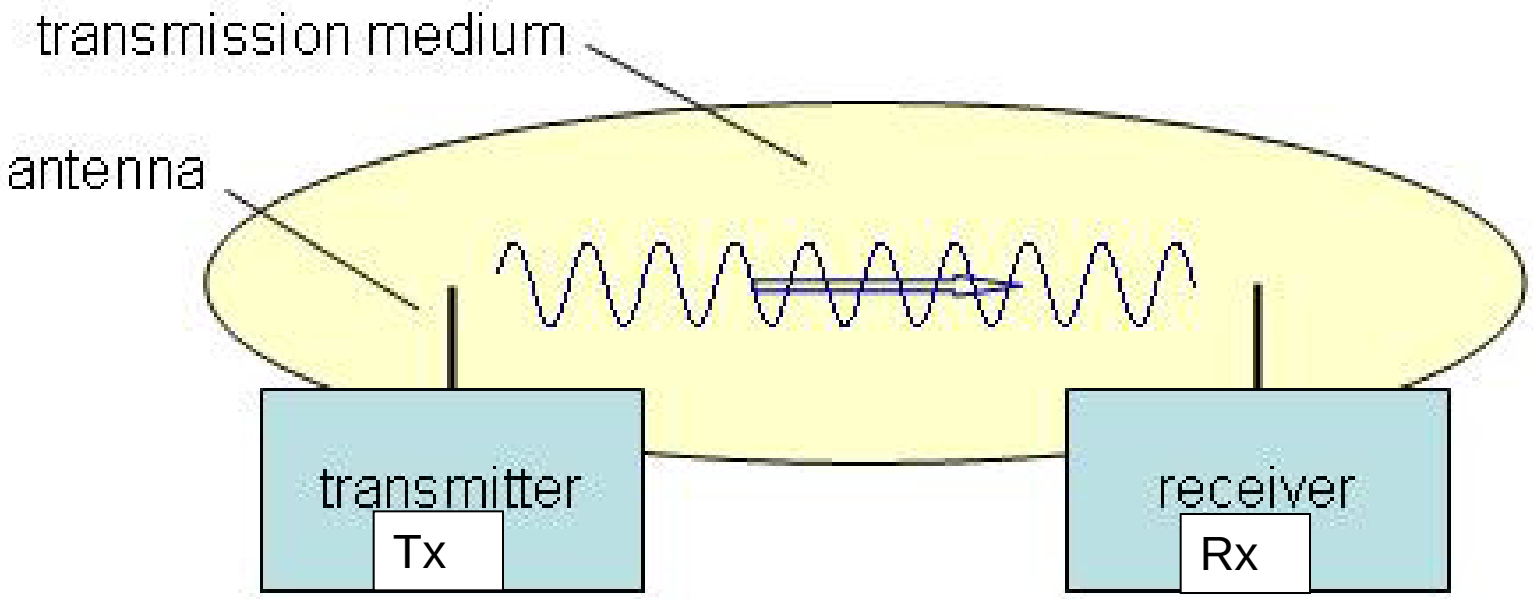
RSSI-Based System

RSSI = Received Signal Strength Indicator

Miner location is based on the estimated distance to each node



RSSI-Based Estimation



The measured loss is used to estimate the distance between the transmitter and receiver: Power Loss = Tx Power – Rx Power

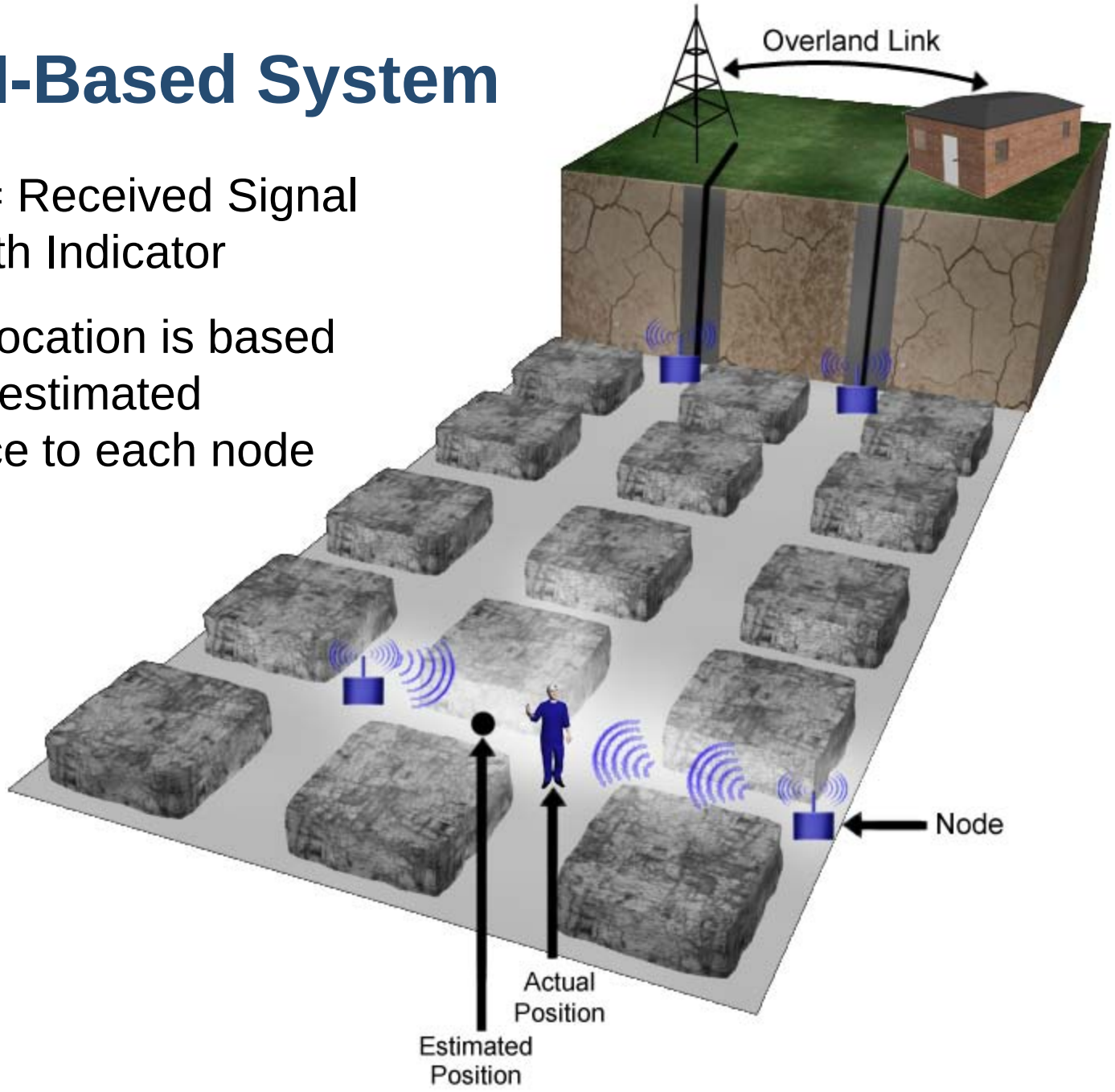
RSSI-Based System

- **RSSI = Received Signal Strength Indicator**
- **Error is the difference between the true location and the RSSI estimated location**
  - With two or more nodes, RSSI techniques can estimate not only how far from the node, but in which entry the miner is likely to be located.
  - With only one node you have the same ambiguity as with a single reader.

RSSI-Based System

RSSI = Received Signal Strength Indicator

Miner location is based on the estimated distance to each node



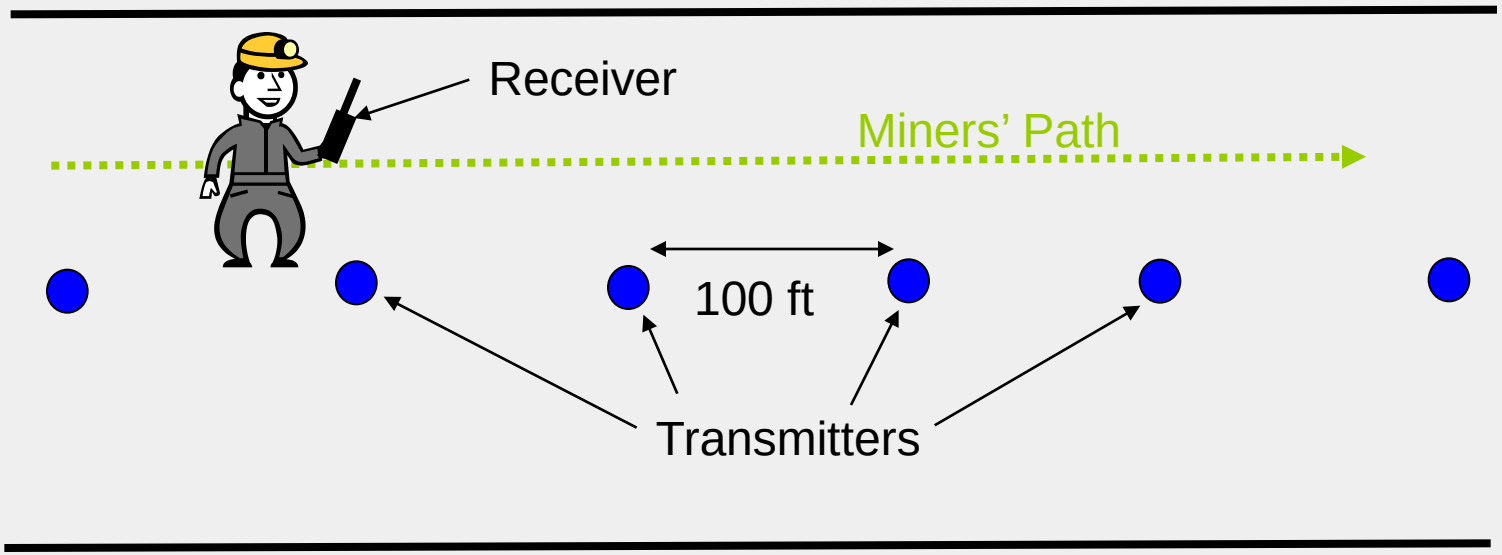
RSSI Error Source

Anything that affects the received signal strength influences the accuracy:

- Wave behavior constructive – destructive multipath
- Body losses reduce signal strength
- Stoppings decrease signal strength
- Mine equipment in the entries affects the signal strength
- Crosscuts, dips, and turns all affect signal strength

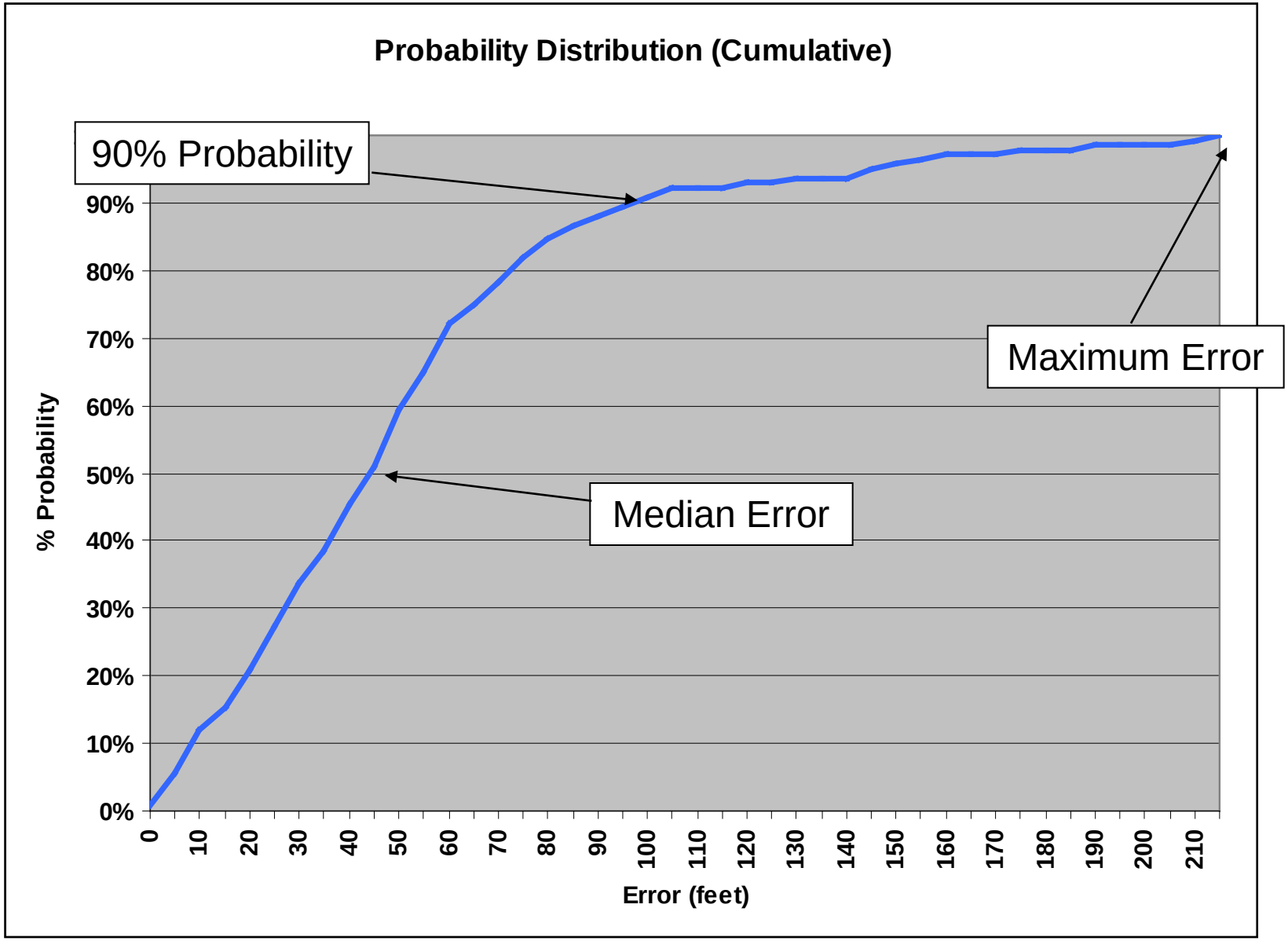
RSSI Error Test

- **Transmitters spaced every 100 ft**
- **Miner walks along entry and true position recorded**

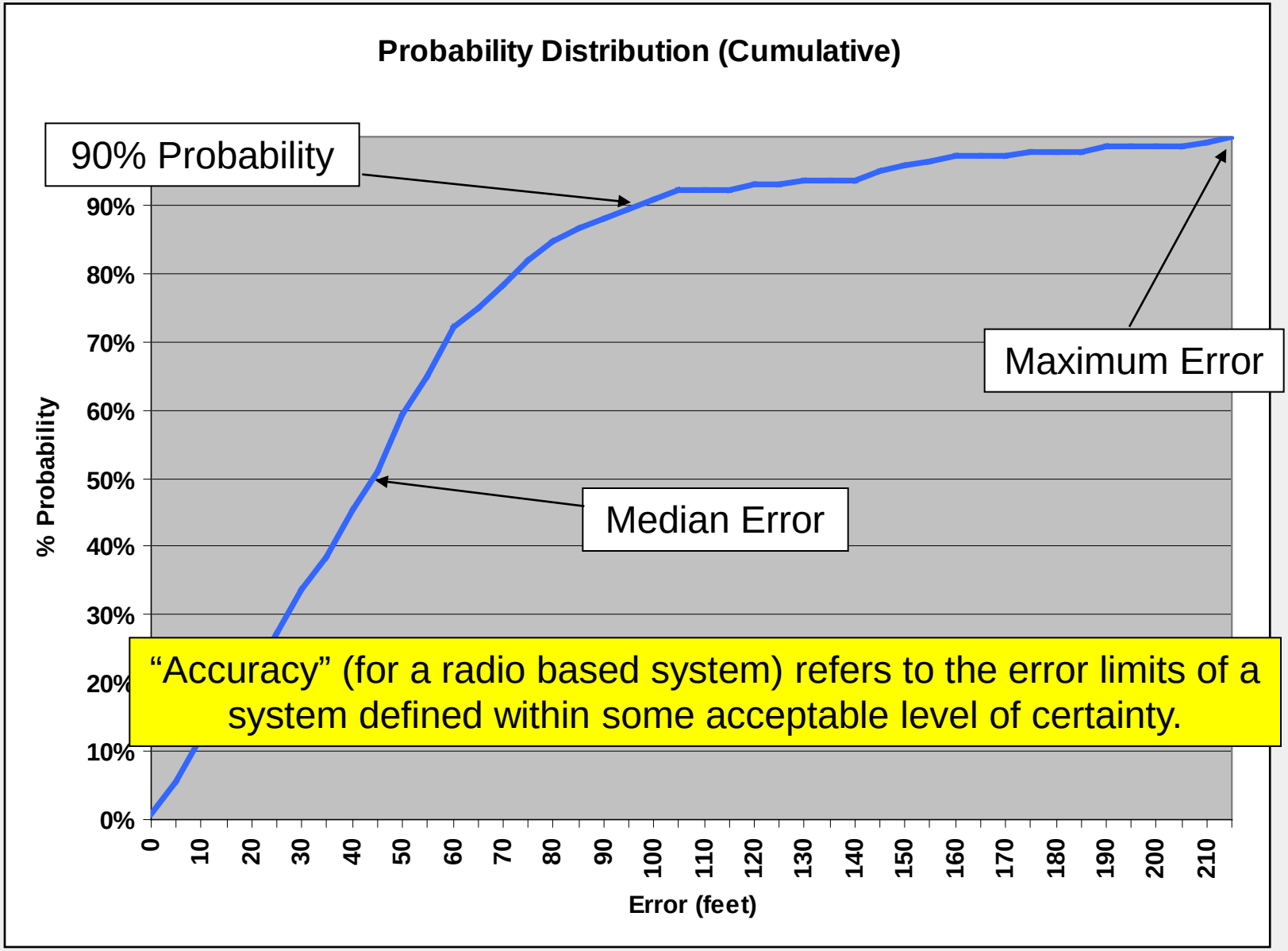


- **Error (true location versus the RSSI estimated location) recorded for each sample point**

RSSI Error Distribution



RSSI Error Distribution



RSSI Error Distribution

- **Accuracy of an RSSI-based system is highly probabilistic (i.e. there is an element of chance)**

- **Without additional processing, RSSI can render an average error of about half the distance between the nodes.**

RSSI Error Correction Techniques

- **There are ways to improve the accuracy, including:**
  - Time averaging of the received signal
  - Considering the rate of travel of the miner
  - Mapping movement to the mine map
  - Time-of-Arrival of the signal
- **Even with these improvements, there is a significant uncertainty. This is not unique to the UG environment; it is inherent to radio frequency-based location systems.**

RSSI Error Correction Techniques

- **RSSI Error Correction improvements are highly dependant on computer processing.**
  - Computer algorithms are proprietary
  - Resources to validate software are extraordinarily high-cost.

- **Neither NIOSH nor MSHA has attempted to validate average or maximum errors.**

Summary

- **Underground communications capabilities are limited by the laws of physics.**
- **An understanding of the operating principles of the C&T systems proposed for UG operations is essential in the design, layout, installation, and operations.**
- **Communication and tracking using radio technology involve some level of uncertainty.**
- **Further information is available in the NIOSH C&T tutorial.**

Questions?

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