An Analysis of an RF Link Budget and RSSI Circuit Design for Long-Range Communications

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***Abstract*— It is important for vehicle drivers to obtain useful information through systems such as a global positioning system (GPS), an intelligent transportation system (ITS), or WiFi data communication. Communication over long distances can be beneficial in many ways. In this paper, an RF link budget calculation for a long range WiFi communication service based on multi-hop communication was introduced, and breakpoint distance and Fresnel zone were calculated to determine the appropriate height of antennas of WiFi repeaters. In addition, this paper demonstrates a received signal strength indicator (RSSI) circuit employed to find the strongest received signal from multiple directions.

***Keywords*— link budget, antenna, switches, received signal strength, received signal detection**

I. INTRODUCTION

Recently, wireless communication technologies have been used to connect people, to control devices or to acquire valuable data. In smart city or smart home applications, an 801.11ah network is convenient; however, it has a limited data communication range of about 1,000m without repeaters [1]. Furthermore, in short distance networks, star-topology networks, through which devices are connected to a central node, have been used [2]. However, in outdoor applications such as vehicle to vehicle communication and vehicle to infrastructure communication, long distance communication based on mesh-topology is necessary. Fig. 1 shows a configuration of long distance multi-hop wireless communication between vehicles and an infrastructure. In mesh networking, each node needs high power devices or outdoor repeaters to be connected directly. Therefore, it is important to calculate a single hop communication distance to lower cost effectively.

The sensitivity of a receiver, antenna location, communication frequencies, antenna gain, and TX power amplifier capacity should be considered when designing a wireless communication system which consists of a TX module, an RX module, and antennas. Furthermore, a land propagation prediction model which takes into account the building and reflection characteristics of RF signals is used [3]. However, in long range communication, the direction of the propagation of incident waves in the atmosphere refracts and waves do not propagate in a straight line while traveling farther.

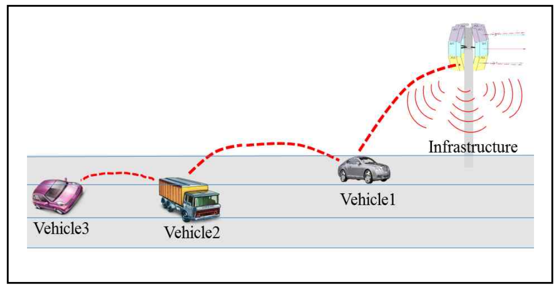

Fig. 1. Wireless communication between vehicles and infrastructure

II. AN RF LINK BUDGET FOR LONG RANGE COMMUNICATION

To design an RF system for long range land communication, environmental and practical characteristics have to be considered, including electrical module specifications. In general, an RF link budget is calculated using frequencies, communication distance, surface scattering, rain, fog and humidity. Furthermore, transmitter output power, antenna gain, and received signal sensitivity are considered. Data throughput also has to be considered in a WiFi system when transmitter power varies by RF communication channel.

When there is difference in antenna beam steering and an object moves, there can be a difference of 20dB between a theoretical RF link budget and a real situation. Therefore, consideration of antenna beam width, antenna location, and antenna type is necessary. For long range communication, the earth's curvature has to be considered with respect to communication distance and the height of antennas. An analysis of multi-ray fading in connection with the surface of the land and reflections of obstacles is necessary.

A. Consideration of Breakpoint Distance

Attenuation of an RF signal is generally influenced by the antenna gain of a transmitter, the antenna gain of a receiver, heights of antennas, and frequencies of communication. Regarding short distance communication, the strength of an RF signal decreases gradually with squared distance. The strength of a signal decreases rapidly after breakpoint when a line of sight (LOS) distance is far. In an

RF link budget calculation for long range communication, breakpoint distance should be considered. Breakpoint can be used to define the size of a microcell and for handoff from one base station to an adjacent base station [4].

In addition, when a communication range is far, transmission loss can be influenced by the height of an antenna regardless of communication frequencies. In short range communication, path loss is affected by frequencies; however, in long distance communication with few obstacles, the height of antennas is a dominant factor determining path loss [5].

As shown in Table 1, regarding a signal of 5.8GHz, and assuming the distance between the Tx point and the Rx point was 15Km, the breakpoint distance was 3.9Km for antennas that were 10m and 5m in height. For antennas that were both 10m in height, the breakpoint distance was 7.7Km. For antennas that were both 30m in height, the breakpoint distance was 69Km. The difference between path loss without considering breakpoint and path loss considering breakpoint for antennas 10m and 5m in height was 12dB. The difference between path loss without considering breakpoint and path loss considering breakpoint for antennas 10m and 10m in height was 6dB. The difference between path loss without considering breakpoint and path loss considering breakpoint for antennas 30m and 30m in height was 0.2dB. High power amplifiers or antennas with high gain is necessary because the value of 6dB or 12dB is critical. However, additional circuits can influence the cost of system implementation.

B. Consideration of Fresnel Zone

For communication over 15Km, the Fresnel zone has to be considered. Waves will start to form new circular waves at each wave front. When a wave hits an object in space, circular waves are diffracted outwards in a semi-circular fashion. When a communication path is long enough, there are direct beams and indirect beams. These RF waves can interfere with each other, and a phase shift of these beams occurs. This phase shift varies from 0 degrees to 360 degrees. There are infinite Fresnel zones; however, the first Fresnel zone has the greatest effect on the attenuation of signal strength [4]. When there is an obstruction, for example, a building, the strength of a wave is diminished. To prevent the loss of wave strength, obstacles have to be considered.

A Fresnel zone can be calculated using parameters such as communication distance and the wavelength of a signal. In this paper, the Fresnel zone was calculated considering communication distance and the height of Tx antennas and Rx antennas. Fig. 2 shows the Fresnel zone and the earth's surface when the antennas were 10m high and 5m high. Signal loss caused by reflection on the earth's surface is shown. Fig. 3 shows the case when both antennas were 10m high, and shows that there were no obstacles between the Tx point and the Rx point. In these cases, the center frequency was 5.8GHz, the distance was 15Km, and the Fresnel zone factor was 0.5.

TABLE I. CALCULATION OF BREAKPOINT DISTANCE AT 5.8 GHZ

Breakpoint and path loss	**Height of the Antennas (Tx Antenna / Rx Antenna)**		
	10m / 5m	***10m / 10m***	***30m / 30m***
Breakpoint	3.9 Km	7.7 Km	69 Km
Free space path loss without consideration of breakpoint	131.0 dB	131.0 dB	131.0 dB
Path loss with consideration of breakpoint	143.0 dB	137.0 dB	131.2 dB

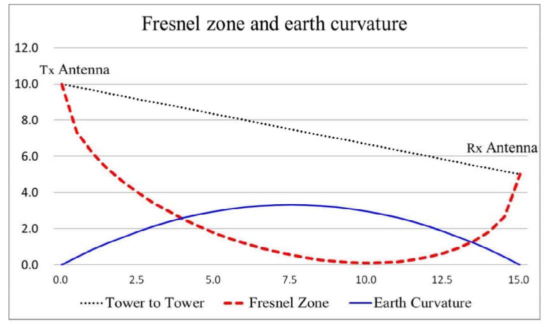

Fig. 2. Fresnel zone for antennas 10m and 5m in height

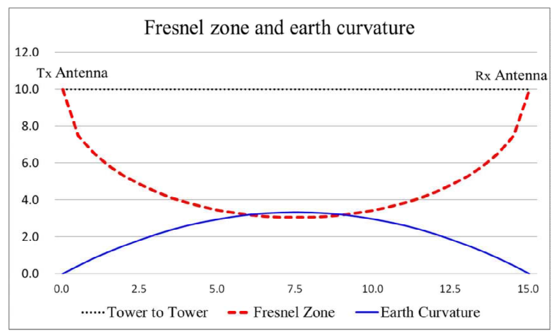

Fig. 3. Fresnel zone for antennas both 10m in height

To compensate for free space loss caused by a breakpoint distance and a Fresnel zone, antenna gain and the output power of a transmitter have to be increased. In vehicles where antennas are installed, the height of the antenna can be limited. However, the repeaters installed on infrastructure can be installed high to enable long range communication. There are two types of antennas, omnidirectional antennas and directional antennas. A directional antenna is more suitable for long range communication. Multi-directional antennas are used for a 360 degrees azimuth coverage, comprising four antennas which have a gain of over 17dB and an azimuth beam width of 90 degrees.

C. A Practical Link Budget Calculation

Table 2 shows an RF link budget for a communication range of 15Km with free space loss of 131dB. The Tx amplifier output power was 2W, the transmitter antenna gain was 17dBi, and the receiving antenna gain was 13dBi. The frequency of communication was 5.8GHz with a link margin of 8dB.

III. Design and Experiment

Fig. 4 shows the structure of an antenna selection switching system which can be applied to WiFi networks. This consisted of three sector antennas, RF switches, power couplers, an RF channel module, a Micro Controlling Unit (MCU), a WiFi interface device, and a received signal strength (RSS) detection module used to detect and compare each signal strength received from three directions. In WiFi technology using time-division multiplexing (TDM), RF switches select a TX path or an RX path depending on controlling signals. Three sector antennas, with an azimuth beam width of 120 degrees to cover 360 degrees horizontally, were used. Fig. 5 shows how to combine each unit in an RSS detection module (RDM). There were two RF switches, a coupler, a band pass filter (BPF), three amplifiers, a detector circuit, and another two RF switches controlled by a time division duplex (TDD) synchronization signal using an MCU.

TABLE II. An RF Link Budget Calculation at 5.8GHz

1. Transmitter			
Frequency	[GHz]	:	5.8
HPA output power	[dBm]	:	33
Cable	[dB]	:	-2
RF swtich	[dB]		-2
Coupler	[dB]	:	-1
Antenna input power	[dBm]	:	28
TX Antenna gain	[dBi]	:	13
Maximum antenna gain	[dBi]	:	17
Gain loss at beam edge	[dB]	:	-3
Polarization mismatch	[dB]	:	-1
Pointing loss	[dB]	:	0
Signal power output (EIRP)	[dBm]	:	41
2. Air channel			
Distance	[km]	:	15.0
Path loss	[dB]	:	135
Free space loss	[dB]	:	131
Rain attenuation	[dB]	:	2
Fog, moisture, etc.	[dB]	:	2
3. Receiver			
Signal power input	[dBm]	:	-94
Efficient RX antenna gain	[dBi]	:	8
Maximum antenna gain	[dBi]	:	13
Polarization loss and others	[dB]	:	1
Cable	[dB]	:	-2
RF swtich	[dB]		-2
Estimated receiving power	[dBm]	:	-86
Receiver sensitivity for 54Mbps OFDM	[dBm]	:	-94
4. Link margin	[dB]	:	8

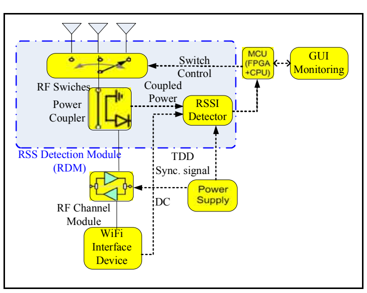

Fig. 4. The structure of an antenna selection switching system

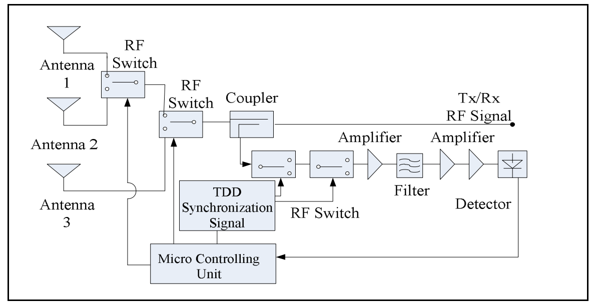

Fig. 5. Received signal strength detection circuit

IV. Conclusion

In this paper, it has been suggested that consideration of breakpoint distance and Fresnel zone is necessary regarding long range communication. According to the RF link budget calculation which considered breakpoint and Fresnel zone, it has been proved that the height of antennas is a critical issue for long range communication. Furthermore, directional antennas with high gain should be used even in Ad hoc long range wireless communication. Each device for an Ad hoc network needs to connect to an access point (AP) after establishing the best communication path by detecting each received signal strength from all directions. To find a suitable AP among many WiFi APs, it is important to detect the strength of signals which are received from each AP. Therefore, an antenna selection switching system can be useful in long distance communication applications.

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