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Non LOS Conditions in Millimeter Wave Band and Proposed Multi-hop Protocol

Nobuhiko Kuribayashi[1] and Wuyi Yue[2]

[1] Siemens K. K., 3-20-14, Higashi Gotanda, Shinagawa-ku, Tokyo, 141-8641, Japan
[2] Department of Information Science and System Engineering
Konan University, Kobe 658-8501, Japan

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Abstract

In this paper, a detailed investigation of millimeter wave Non LOS (line of sight) conditions and proposed multi-hop protocol is described. Ratio under received power threshold is calculated by measuring the complex permittivity of a used desk and propagation loss characteristics along the surface of a desk plane. This calculation result shows Non LOS conditions existence even though line of sight is secured on the desk environment. Visibility estimation in the typical Japanese office is calculated using light emission method and shows high rate of Non LOS condition. In order to minimized Non LOS conditions, multi hop protocol is proposed. Terminal BER profile is used for finding to the most suitable extension point (EP). The use of twin link communications and an automatic handover mechanism, which are minimized to Non LOS condition, are proposed.

Keywords: Millimeter wave band, multi-hop protocol, Non LOS condition, propagation loss characteristics.

1. Introduction

Wireless personal network (WPAN) and wireless local area network (WLAN) using microwave band have been established worldwide. These systems have several ten Mbps transmission data rate and are used for connecting PC, PDA, game machine, AV home server, home electric appliances, etc..

However, high data rate demands for short-range communications are ever increasing. The current target transmission speed of short-range communications is presently 1Giga bps due to the popularity of Giga bit Ethernet interface. Users would like to use high wireless transmission at the same speeds as wired communication.

To achieve Giga bps transmission speed, the frequency bandwidth required is several hundred MHz. With respect to the frequency band, millimeter-waves such as a 60/70 GHz band is considered to be the best for short-range high-speed wireless applications based on the spectrum width and lesser degree of interference characteristics.

In addition to the high transmission speed demands, there are demands for easy connectivity and network flexibility. Authors propose millimeter wave ad-hoc wireless access systems including a millimeter wave wireless PC card that is installed at a low height of several centimeters above a desk. Line of sight (LOS) has to be kept mandatory for millimeter wave communication because of millimeter waves huge propagation loss.

In order to develop millimeter wave ad-hoc access systems, investigation of Non LOS conditions including, visibility and new protocol to minimize Non LOS conditions, have been required.

This paper highlights the investigation of Non LOS conditions in millimeter wave band on the influence of receiving power distribution along the surface of a desk plane, as well as the investigation of visibility estimation on desks in a typical Japanese office. Resulting from this Non LOS condition investigation is the proposed use of multi-hop protocol that has been adapted for millimeter wave. This is proposed in order to overcome and/or minimize Non LOS conditions.

The remainder of the paper is organized as follows. In Section 2, we give the Non LOS conditions. In Sections 3, we provide a multi-hop protocol and discuss the configuration, configuration control and operation of the multi-hop protocol. Section 4 contains the paper's conclusions.

2. Non LOS Conditions

2.1 Complex permittivity

The measurement of complex permittivity for a wooden desk was carried out in an anechoic chamber. The measurement equipment is shown in Fig. 1 (see [1]).

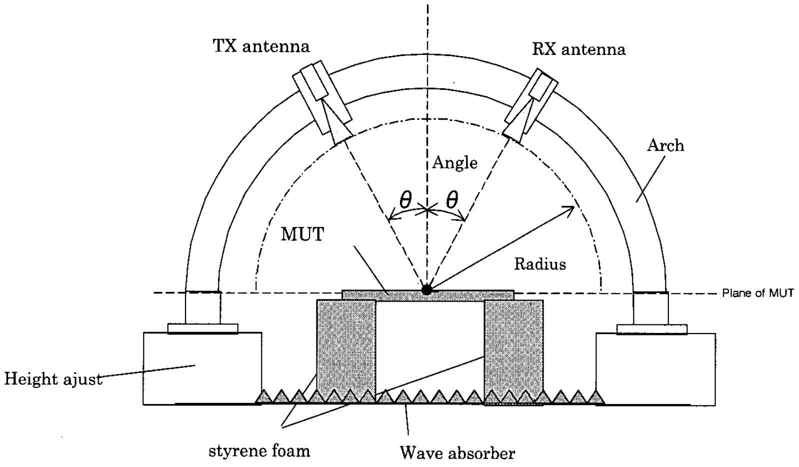

Fig. 1. Complex permittivity measurement equipment.

The transmitting antenna and the receiving antenna were attached to a wooden arch, and the distance between a measurement sample and an antenna opening side was set to 1m. Measurement sample is a wooden desk that is a concrete object and is used for the millimeter wave ad-hoc communication experiment.

The measured sample was installed on styrene foam. The wooden desk shown MUT (Material Under Test) in Fig. 1 was installed on styrene foam. The wave absorber was installed in the bottom of the styrene foam. In addition to this, a second wave absorber was installed on floor side surrounding the measurement equipment.

The unnecessary reflective wave other than the reflective wave from a measurement sample and the direct wave between antennas are eliminated by the wave absorbers on the floor.

Measurement conditions are shown in Table 1. The reflection wave is measured when a sample is installed and the reflective coefficient is computed on the basis that the aluminum board was installed as a 100% reflection reference. In addition, the incidence angle was set as from 5 degrees to 80 degrees so that direct waves between the transmitting antenna and the receiving antenna would not influence measurement results.

Table 1. Complex permittivity measurement conditions.

Distance between materials and antenna	1 m
Antenna	Wave guide horn antenna
Polarization	Vertical, Horizontal
Measured incident angle	5 to 80 degrees every 5 degrees
Frequency	70GHz
Measured equipment	Network Analyzer (HP8510C, Agilent inc.)
Reference	Aluminum plate (1m × 1m 3mm thick)

The horizontal polarized wave reflection coefficient Γ_H and the vertical polarized wave reflection coefficient Γ_V can be written as [3]:

$$\Gamma_H = \frac{\cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}}, \tag{1}$$

$$\Gamma_V = \frac{\varepsilon_r \cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\varepsilon_r \cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}}. \tag{2}$$

In the above equations (1) and (2), since ε_r is a complex value.

The measured values of horizontal wave and vertical wave are plotted in Fig. 2. Theoretical values of horizontal wave reflection coefficient and vertical wave reflection coefficient are also plotted in Fig. 2, dispersions of difference between the theoretical curve of equations (1) and (2) and the measured values is minimized by adjusting the real part and the imaginary part of ε_r. The complex permittivity of the wooden desk is calculated at the most minimized point of the dispersion of the vertical wave and the horizontal wave [4]. The obtained complex permittivity of the wooden desk is 4.14 + 0.15i.

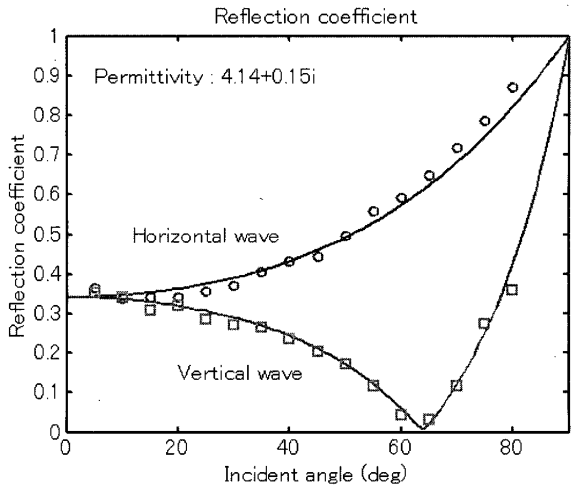

Fig. 2. Measured complex permittivity of the used wooden desk.

2.2 Desk propagation model

In this model, in addition to a straight path, there is a reflected wave path bouncing back from the plane towards the receiver as shown in Fig. 3 (see [2]). The two paths will combine at the receiver with a phase difference related to the path length difference of the two rays. In Fig. 3, h is the height of the antennas, D is the ground distance between the antennas, d1 is the distance along a direct path between the antennas, and d2 is the length of the reflected path bouncing back from the plane towards the receiver, respectively.

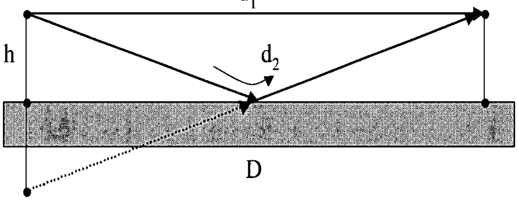

Fig. 3. The reflective plane scenario.

Then, it can be written that:

$$d_1 = D$$

and

$$d_2 = \sqrt{4h^2 + D^2}\,.$$

$(d_2 - d_1)$ will then be:

$$d_2 - d_1 = D\left[\left(\left(\frac{2h}{D}\right)^2 + 1\right)^{\frac{1}{2}} - 1\right].$$

Since the antenna heights are small compared with the total path length, the following approximation can be used from the binomial theorem:

$$(1+x)^n \approx 1 + nx\,,$$

namely,

$$d_2 - d_1 = \frac{2h^2}{D}\,.$$

And the corresponding phase difference will then be:

$$\phi = \frac{4\pi h^2}{\lambda D}\,.$$

Since the path length is large (4m) compared with the antenna heights (8cm), the two rays arrive with similar magnitudes apart from the reflection loss, Γ. The overall amplitude will then be:

$$A_{total} = A_{direct} + A_{reflected}\,,$$

$$A_{total} = A_{direct}\left|1 + \Gamma \exp\left(j\frac{2\pi}{\lambda}\frac{2h^2}{D}\right)\right|.$$

Power is proportional to the amplitude squared, that is:

$$\frac{P_R}{P_{direct}} = \left(\frac{A_{total}}{A_{direct}}\right)^2$$

where P_R is the received power, which gives:

$$\frac{P_R}{P_{direct}} = \left| 1 + \Gamma \exp\left(j \frac{2\pi}{\lambda} \frac{2h^2}{D} \right) \right|^2 .$$

The transmitted power, P_T, of the direct path suffers some free space path loss as:

$$P_{direct} = P_T \left(\frac{\lambda}{4\pi D} \right)^2 .$$

As a result, the path loss can be written as:

$$\frac{P_R}{P_T} = \left(\frac{\lambda}{4\pi D} \right)^2 \left| 1 + \Gamma \exp\left(j \frac{2\pi}{\lambda} \frac{2h^2}{D} \right) \right|^2 \tag{3}$$

where P_R is the received power, P_T is the transmitted power, Γ is the reflection coefficient, and λ is the wavelength.

The horizontal polarized wave reflection coefficient Γ_H, the vertical polarized wave reflection coefficient Γ_V can be written as equations (1) and (2). The circular polarized wave reflection coefficient (forward direction) Γ_C, and the circular polarized wave reflection coefficient (reverse direction) Γ_X can be written as [3]:

$$\Gamma_C = \frac{\Gamma_V + \Gamma_H}{2} , \tag{4}$$

$$\Gamma_X = \frac{\Gamma_V - \Gamma_H}{2} \tag{5}$$

where ε_r is the complex permittivity, and θ is the incident angle.

2.3 Ratio under received power threshold value

The transmitting antenna (x, y) is located at origin (0, 0). When the receiving antenna is placed at (x, y), the received power distribution is calculated by the equation (3) shown in Fig. 4. The vertical axis of Fig. 4 shows received power.

Calculated condition is shown in table 2. In a case where the received power threshold is –80dBm, the area colored white shows the area under the received power threshold according to the link budget calculation in Fig. 5.

Calculation results of ratio under received power threshold are 12.25% for the horizontal polarized wave, 11.06% for the circular polarized wave and 9.88% for the vertical polarized wave, respectively. This calculation result means that no receiving area exists even though line of sight is secured in a millimeter wave propagation environment.

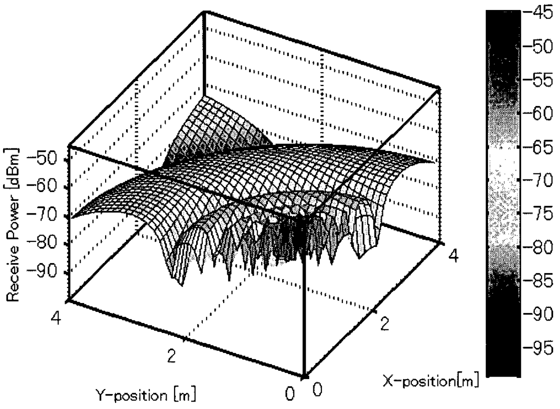

Fig. 4. Received power distribution (horizontal polarized wave).

Table 2. Received power calculated conditions.

Frequency	70GHz
Antenna	Omni antenna 0dBi
Polarization	Horizontal polarized wave Vertical polarized wave Circular polarized wave
Antenna height	10cm
Transmitting power	10dBm
Mesh size	10cm × 10cm

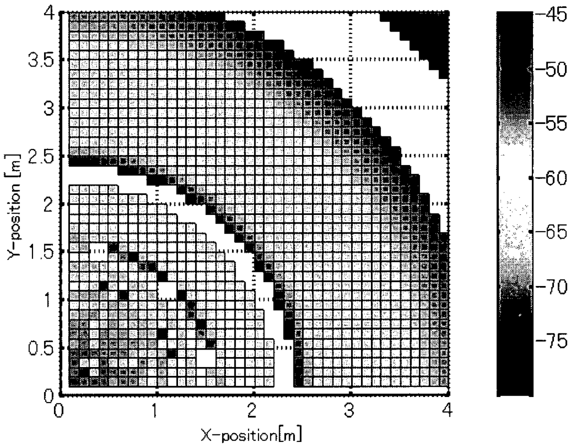

Fig. 5. Received power distribution (*x*-*y* plane) (horizontal polarized wave).

2.4 Visibility estimation

Indoor visibility simulation was carried out for a typical Japanese medium-size office using the light emission method (LEM). The office dimensions were 12m(L) × 8m(W) × 3m(H). Fig. 6 depicts the interior layout of the modeled office. Desks and 12 PCs used as obstacles for light rays on the desks were also positioned in the office. The test simulated two cases of indoor visibility. One case assumes no-one is in modeled office. The other case assumes that 24 people are sitting at their desks.

The visibility simulation results are shown in Fig. 7 (see [5]). Only one Master Station is located on the center of the ceiling. The simulated height of the light source (Master station) is from 1.5m to 3m. In this simulation, the definition of visibility estimation is the sum of the lighted area on the desks divided by the total desk surface area. The result is expressed as a percentage. The visibility estimation with people in the office reaches 82.3% at 3m-height and 50% at 1.5m-height. To maintain the visibility in the case where only a Master station is available, a height of at least 2.5m is required to avoid inference from the bodies in a propagation environment.

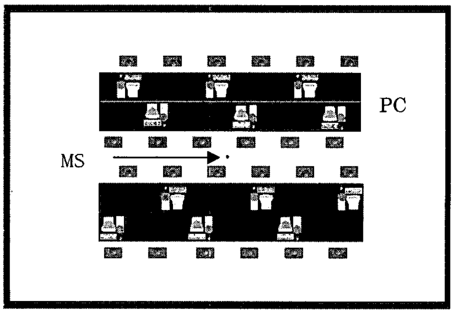

Fig. 6. Interior layout of modeled office.

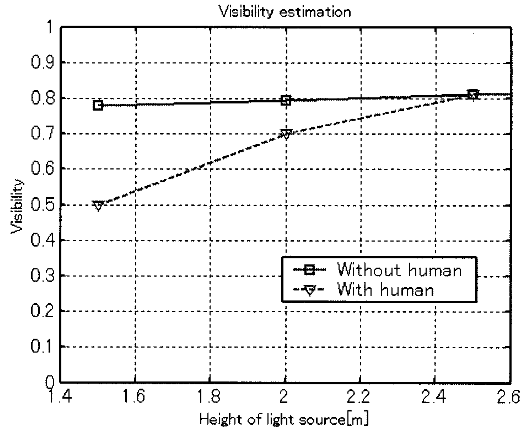

Fig. 7. Visibility simulation result.

3. Multi-Hop Protocol

In Ad Hoc wireless access systems with a millimeter wave frequency band, a well-known problem is the huge path loss. To alleviate this problem, it is necessary to guarantee a Line of Sight (LOS) condition between the transmitting antenna and the receiving antenna.

However, there are 9.88%-12.25% non-received power areas on the desks described in Section 2.3 in case of LOS. This means equivalent to shadowing effects even through a line of sight condition is secured. As described in Section 2.4, the visibility estimation in the typical Japanese office when the base station is installed at a height of 1.5m and people are present is 50%.

Out of visibility estimation means that there is an object between a transmitter and a receiver, creating a large shadowing effect that prevents the maintaining of the communication.

In millimeter wave band, Non LOS problem is one major challenge that has to be considered when the system is developed.

Keeping an adequate communication distance is also a topic that needs to be considered because of the limited output power and huge path loss in millimeter wave band.

In order to minimize the negative impact on the communication quality, the application of multi-hop protocol is proposed and explained in this section.

3.1 Configuration of multi-hop protocol

A terminal can be configured as Master (MS), Slave (SL) and Extension Point (EP). Master (MS), Slave (SL) and Extension Point (EP) are all terminal type and configurable dynamically by the protocol.

The MS has router functions and generates and updates a terminal bit error rate (BER) profile periodically. It also specifies the terminal as SL or EP according to the terminal BER profile.

The EP forwards data between SLs and the MS. The EP also communicates as a MS for the EP itself. Single-and double-hop connections between SL's and the MS will be supported, i.e. more than one SL can be connected to the MS either directly or via an EP.

3.2 Configuration control of multi-hop protocol

After starting up, SLs located within the range of the MS will synchronize randomly to the MS. The MS recognizes a number of SL's and the MS forces SL's toward an EP one by one in order to obtain the terminal BER profile shown in Fig. 8. According to terminal BER profile, the MS decides the most suitable EP that has a maximum number of connections exceeding the BER threshold value. MS updates terminal BER profile periodically shown in Fig. 9. In order to generate and update the terminal BER profile, dedicated signaling channels are required in an up and downlink direction. These signaling channels are transmitted before the payload data and use the most robust PHY mode (i.e. BPSK, R=1/2).

3.3 Operation of multi-hop protocol

Fig. 10 shows the simplified MAC frame structure of multi-hop protocol [6], [7]. In Fig. 10, preambles and idle intervals have been omitted for clarity. TDD/ TDMA is used in this system.

BC (MS) and BC (EP) are used for MS broadcast signal time slot and EP broadcast signal time slot respectively. MS-SL/EP and EP-SL are MS downlink time slot and EP downlink time slot respectively. EP-MS and SL-EP are EP uplink time slot and SL uplink time slot, respectively.

EP receives broadcast signal from BC (MS) time slot, then, EP re-transmits broadcast signal using BC (EP) time slot. SL selects to receive BC (MS), MS-SL/EP for MS communication or BC (EP), EP-SL for EP communication by BER measurement of MS-SL connection and EP-SL connection.

Fig. 11 shows a MS, SL and EP configuration without any obstacles. MT keeps watching 2 links: MS -SL and MS - EP- SL. SL uses the better link to access MS. An automatic handover is used for switching between MS-SL connections and MS-EP-SL connections.

An automatic handover attempt occurs if the SL looses the frame synchronization by the obstacles described in Fig. 12. In this case, the hardware handles the re-synchronization without any software interaction. If the re-synchronization is successful, the MS application software will not even notice the temporary sync loss. Handover algorithm uses measured BER value and includes a mechanism for avoiding oscillating.

3.4 BER measurement mechanism

The BER measurement method follows these three steps.

(1) Encodes the output of FEC decoder and regenerates the input data of the FEC decoder.

(2) Delays the input to the FEC decoder to coincide with the FEC encoding time.

(3) Calculates the BER by comparing the above (1) and (2).

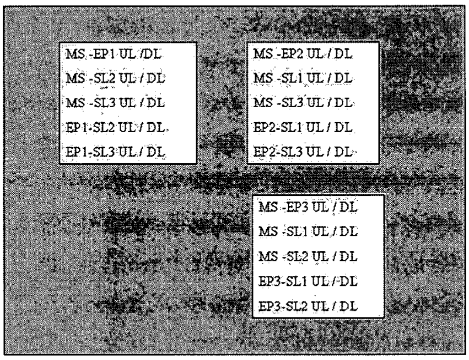

Fig. 8. Terminal BER profile.

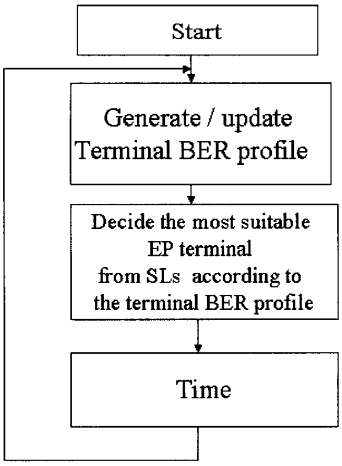

Fig. 9. Configuration control.

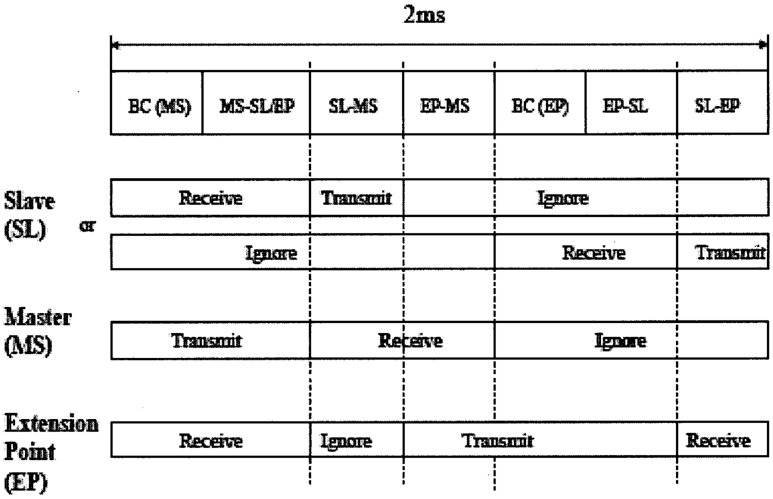

Fig. 10. Simplified MAC frame structure of multi-hop protocol.

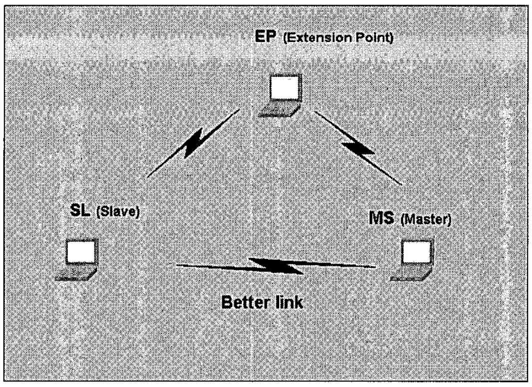

Fig. 11. Multi-hop protocol concept (case 1).

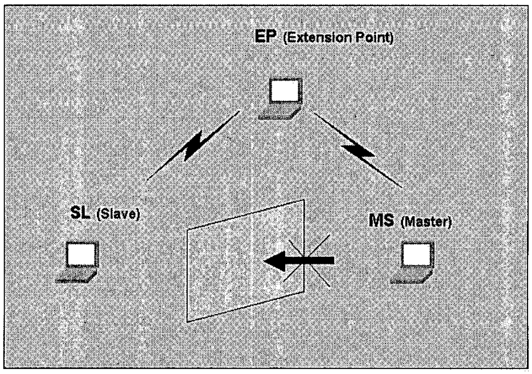

Fig. 12. Multi-hop protocol concept (case 2).

4. Conclusions

In this paper, a detailed investigation of millimeter wave Non LOS (line of sight) conditions and proposed multi-hop protocol is presented.

Ratio under received power threshold is calculated by measuring the complex permittivity of a used desk and propagation loss characteristics along the surface of a desk plane. This calculation results are 12.25% for the horizontal polarized wave, 11.06% for the circular polarized wave and 9.88% for the vertical polarized wave for 10cm high antennas on 16 square meters of desktop on a 70GHz band and shows non LOS conditions in existence even though the line of sight between antennas is secured on the desk environment.

Visibility estimation in the typical Japanese office calculated using light emission method shows about 50% at a height of 1.5m. This value is very large and poses a big problem for millimeter wave communication considering that line of sight is a mandatory requirement due to huge propagation losses in millimeter waves.

In order to overcome and minimized Non LOS conditions, multi hop protocol is proposed. In this protocol, Terminal BER profile is generated and updated for periodically deciding the most suitable extension point (EP). This mechanism provides the most robust network by assigning and updating a suitable EP.

Two link communications and an automatic handover mechanism minimize Non LOS conditions and the hardware handles the re-synchronization without any software interaction.

Acknowledgment

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