Employing Millimeter-wave Systems with Small Size Antennas in Street Canyons: Thoughts and Experiments

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Abstract:
The future is likely to see millimeter-wave systems used in urban street canyons for high data rate communications. Space limitations in urban areas will necessitate using small size antennas for building millimeter-wave systems in mobile front-haul application. Such antennas have broad beamwidth and consequently the systems in street canyons will incur multi-path interference. This letter addresses the issue of such multi-path interference. We conducted experiments in 72 GHz bands to ascertain the interference effects and a strategy we devised for avoiding them. We found that harmful interference can be evaded by rotating the radio transmission direction.

Keywords: millimeter-wave, experimental evaluation, fixed radio communications, mobile front-haul networks

Classification: Wireless communication technologies

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1 Introduction
In the fifth generation (5G) mobile systems, using small cells and radio bands above 6 GHz enables the user terminals to have 20 times of bandwidth than those of current 4G-LTE systems [1]. It is generally considered that the small cells need to be ultra-densely deployed, which raises new cost problems on building mobile front-haul (MFH) networks in urban areas [2, 3]. Building MFH by millimeter-wave (mmW) systems is a promising solution, since the considerable bandwidth in mmW bands can meet the high data rate requirements (e.g., 10 Gb/s) of the small cells. Moreover, the short wavelength (<5 mm) of millimeter waves makes it possible to scale down the physical size of antenna and implement antenna arrays for beamforming or massive MIMO [3].

On the other hand, using mmW systems as MFH is a new challenge. Due to the small cells are placed on the pole of lampposts or the roof of bus stops, the mounting space is strictly restricted. Conventional high gain antennas for mmW systems, e.g. a parabolic one with 30 cm aperture size will no longer be suitable for the MFH usages. Thus, small size antennas are required.

A mmW channel dominated by line-of-sight (LOS) propagation still have multi-path components in street canyons [4], and multi-path waves could interfere mmW systems. In this letter, we report how we performed experimental evaluations to ascertain the multi-path interference issue that incurs in street canyons. By conducting practical measurements on a commercial system with small size antennas, we clarify the effects of multi-path interference. Also, we verify a strategy developed for avoiding the interference.

2 Issue of system with small size antennas
High path loss makes it necessary to use directive antennas in mmW systems. In the past, high gain antennas are mounted on the top of towers without space limitations. There are also no reflectors nearby, and the antennas’ narrow beamwidth (<1°) made it possible to get rid of multi-path interference easily.

However, novel MFH usage made it possible to use mmW systems in street canyons, where reflectors included in the environment made multi-path interference incurring. A typical street canyon example is shown in Fig.1, where Building #1 and Building #2 are parallel to each other. Let us assume the transmitter (TX) and the receiver (RX) of the mmW system deployed in front of the buildings and their main beams are well aligned. Between the TX and the RX, the direct wave is shown by the bold arrow. The multi-path wave(s) reflected by the buildings will also occur between the TX and the RX. In order to draw the diagram simply, we show only one multi-path wave representative (the dotted line).

Unlike conventional high gain antennas, using a small size antenna means a broader beamwidth of main beam and a higher risk that the RX will receive more unwanted multi-path waves. The multi-path waves cause an inter-symbol interference problem if their power exceeds a certain level compared to the power of direct wave. This inter-symbol interference is harmful because it causes the RX to get high bit error rate (BER) from the received radio signals. To meet the high data rate requirement for MFH, it necessitates wideband radio signals to be
transmitted and received between TX-RX with high reliability (i.e., very low BER). Such wideband radio signals are often modulated by higher-order quadrature amplitude modulation (QAM), and they are very susceptible to inter-symbol interference. Thus, it is necessary to address the issue of multi-path interference that incurs in street canyons with small size antennas.

![Diagram of multi-path interference](image)

**Fig. 1.** Simplified diagram for the multi-path interference issue. In addition to the direct wave, multi-path wave(s) reflected by Buildings #1 and #2 may cause inter-symbol interference in TX-RX.

### 3 Deploying strategy to avoid multi-path interference

In this section, we discuss a way to avoid multi-path interference. We assume the main beams are perfect aligned between TX-RX and multi-path interference incurred by the second order reflection from the buildings.

When deploying TX-RX in a street canyon, if we let the direction of direct wave be perpendicular to the parallel buildings, then the reflected multi-path waves will exist on the center of the main beams and cause the worst interference case.

If we assume mirror reflection by the buildings, the multi-path waves will follow the law of reflection. By rotating the radio transmission (direct wave) direction from the perpendicular lines of the parallel buildings, we can expect the reflected multi-path waves will deflect away from the direct wave direction (the center of the main beams), go toward the edge, and finally go outside of the main beams. Thus, a deploying strategy of rotating the direct wave direction will enable the antenna directivity to mitigate the multi-path interference and protect the radio signals.

In a street canyon, the multi-path interference and how far a rotating angle is required for avoiding it is not obvious but needs to be verified. Therefore, we use experimental measurements to evaluate the multi-path interference and the deploying strategy to evade it in a real environment.
4 Experimental measurement and result verification

On the left hand side of Fig. 2, we show the geometrical locations for measurements. We fixed the TX point (white dot) at \( t_0 \) throughout all the measurements. We moved the RX point (black dots) in each measurement, as a variable to control the rotating angle \( \angle r_0 t_0 r_i = \angle \theta_i \) from the perpendicular line of the buildings. Distinct RX points are equally separated by \( X \). The distance between two parallel buildings is given by \( D \) and the shortest distance of TX-RX is \( t_0 r_0 = L_0 \). The \( t_0 r_i \) distance (black line) can be defined as \( L_i = \sqrt{L_0^2 + (iX)^2} \).

For each measurement, the rotating angle for TX-RX can be calculated by \( \angle \theta_i = \cos^{-1}(L_0/L_i) \). We started the measurements from the worst-case \( \angle \theta_0 = 0 \). After increasing the rotating angle \( \angle \theta_i \) in each measurement, we steered the TX and the RX to align their main beams and then we monitored the RX’s BER performance. We are particularly interested to search for the minimum rotating angle that would enable us to avoid harmful interference.

For mmW radio transmission, we employed an E-band (70/80 GHz) radio equipment set able to deliver the maximum throughput of 10 Gb/s. To our best knowledge, this commercial radio equipment set has enough throughput to meet the high data rate requirement for MFH. The radio frequency we used in the experiment was 72.1 GHz and the radio transmission power was 10 dBm. The
A wideband radio signal was 2 GHz channel bandwidth and modulated with 128QAM.

For studying the interference issue and comparing the interference mitigation effect in accordance with antenna directivity, we used two different set of horn antennas: type 1 and type 2. They had respectively 10° and 14° half-power beam width (HPBW), 23 dBi and 20 dBi typical antenna gain, and 2.71 cm × 2.22 cm and 2.0 cm × 1.6 cm size factor. Both antennas had vertical polarization and were set 1.6 m above the ground level for all measurements.

The results in Fig. 3(a) show that the interference was harmful when $\angle \theta_i$ was smaller than the minimum rotating angle shown above. Due to the function limitation of real-time monitoring in the radio equipment set, we could only display detailed BER in the range of $(10^{-3}, 10^{-10})$. Outside the display range, we could only obtain gross information of BER $\geq 10^{-3}$ and BER $\leq 10^{-10}$. The results of BER $\leq 10^{-10}$ mean that no interference issue incurred. From the results in Fig. 3(a), it requires the minimum rotating angle to be 9° with antenna type 1 and 11° with antenna type 2 for evading the interference. With narrower beamwidth of main beam, the E-band radio equipment set with antenna type 1 had a smaller

![Graph](image_url)
rotating angle to evade the multi-path interference than for antenna type 2.

To verify the measurement results, we analysis that why the BER is improved at the specified rotating angle. As explained in section 3, the power ratio of direct wave to unwanted multi-path interference (DUR) can be improved by rotating the transmission direction of direct wave. We show an estimation of DUR in Fig. 3(b). For calculating the DUR at the corresponding rotating angle, we used the Friis’ transmission model. For the directivity gain, we referred the radiation patterns of antenna type 1 and antenna type 2 which are shown in their data sheets. Also we assumed that the unwanted interference wave is the second order reflection only and the reflection loss can be neglected. From Fig. 3(b), we could found that at the minimum rotating angles where the BER is improved, i.e., 9° with antenna type 1 and 11° with antenna type 2, their DUR exceeded a certain level.

5 Conclusion
In this letter, we described the issue of multi-path interference incurring in street canyons. By experimental measurements, we clarified a strategy that rotating the radio transmission direction avoids the interference. This makes it possible for a modern radio equipment set to deliver at 10 Gb/s. Experiment results showed that the minimum rotating angle was 9° required for antennas with 10° half-power beamwidth (HPBW), and that it was 11° for antennas with 14° HPBW to avoid the multi-path interference in a real street canyon.

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