Bandwidth requirements for accurate detection of direct path in multipath environment

Z. Tarique, W.Q. Malik and D.J. Edwards

The accurate detection of the direct path in a dense multipath environment is critical in time-based and angle-of-arrival-based location estimation techniques. It is generally assumed that an infinitely large bandwidth is helpful in the accurate detection of the direct path and high-range resolution. It is experimentally demonstrated that, for a wideband system, a bandwidth of up to 4 GHz, centred on 12.5 GHz, is sufficient for accurate detection of direct path in a typical indoor scattering environment. Additionally, the bandwidth gain, incremental range accuracy with bandwidth, is an effective indicator of the bandwidth requirements for accurate detection of the direct path.

Introduction: In 1996, the US Federal Communications Commission enacted a regulation, requiring wireless service providers to report the E-911 callers' locations to the public safety answering points [1]. In 2003, the European Commission (EC) also approved a recommendation requiring service providers to pass E-112 callers' locations to emergency centres [2]. Extensive research has therefore been carried out to improve the wireless position estimation accuracy.

As compared to narrowband signals, wideband signals provide finer time resolution, enabling higher multipath resolution and ranging accuracy. These features are useful in numerous applications, such as sensor networks, package tracking in warehouses, monitoring of patients in hospitals, wireless positioning of fire fighters and rescue teams during natural disasters like earthquakes and floods, and controlling of home appliances [3]. All of these applications require different levels of position estimation accuracy.

In time-of-arrival (TOA) and angle-of-arrival (AOA) based locationing techniques, the major source of error is the detection of the direct path in a multipath environment. There are two types of errors associated with multipath environments: early false alarm error and missed path error [4]. For accurate location estimation, both of these errors have to be minimised.

In this Letter, the effect of bandwidth on location estimation accuracy for a wideband system is investigated. It is shown that the ranging accuracy increases with bandwidth. However, the bandwidth gain, defined as the decrease in the ranging error with an increase in the bandwidth, diminishes with the measurement bandwidth. An analysis based on measured data is presented below.

Measurement setup: The measurements were conducted in a 6 × 6 m room over a bandwidth of 5 GHz (10–15 GHz) with 1601 frequency points. The room was populated with computers and metallic filing cabinets, which provided a rich scattering environment. Discone omnidirectional antennas [5], mounted 1.8 m above the floor, were used in the measurements. A vector network analyser (VNA) based channel sounder was used for measurements [6]. The receive antenna was mounted on an x–y positioner, while the transmit antenna was fixed. Three separate sets of measurements were taken with the transmit antennas placed at different positions within the room at distances of 1.81, 2.57 and 3.09 m from the x–y positioner. Signal distortion due to transmit and receive antennas was considered part of the channel transfer function.

Analysis and results: The channel transfer function was divided into five frequency bands of 1, 2, 3, 4 and 5 GHz, respectively, while keeping the centre frequency at 12.5 GHz. The frequency-domain measurements were windowed and an inverse fast Fourier transform was applied to obtain the complex channel impulse response (CIR). The CIR consists of a direct path, reflected paths and background noise. A threshold was applied to the CIR to suppress the noise and reflected multipaths that were 10 dB below the dominant multipath.

The root mean square ranging error (RMSRE) is used as the measure of range estimation accuracy. Fig. 1 shows the cumulative distribution function (CDF) of the RMSRE at various bandwidths. At each spatial grid point the RMSRE is calculated from all three transmit antennas. The decrease in the ranging error, the bandwidth gain, is greatest when increasing the bandwidth from 1 to 2 GHz and it diminishes as the bandwidth is further increased, showing the relationship between bandwidth gain and bandwidth is not linear. This is because the number of multipaths and their relative propagation delays depend on the location of reflecting and scattering surfaces around the antennas. An increase in the bandwidth enhances the timing resolution of the measurement and aids the resolution of signal paths in the dense multipath environment, which is critical for TOA and AOA based location techniques. If the bandwidth is large enough to identify the direct path from the multipath clutter then any further increase in bandwidth will not provide any more gain in the range resolution.

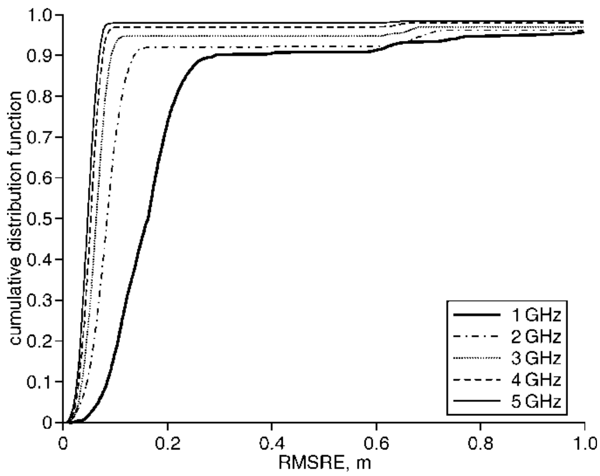

Fig. 1 *CDF of RMSRE for various measurement bandwidths*

Fig. 2 shows RMSRE at the 50th, 60th, 67th, 70th, 80th and 90th percentile for various bandwidths. The RMSRE decreases exponentially with bandwidth. For comparison the variation of range resolution, Δr, with bandwidth, B, for a one-way communication link is also drawn. The range resolution is defined as $\Delta r = c/B$, where c is the speed of light. From Fig. 2, the bandwidth gain at a particular bandwidth can be calculated by taking the first derivative of the RMSRE curve.

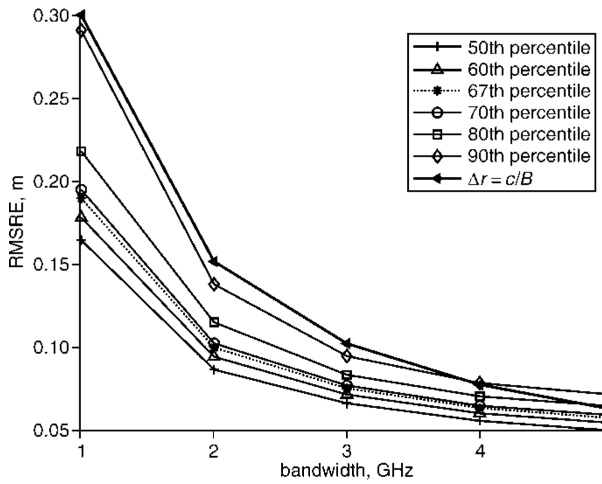

Fig. 2 *RMSRE at 50th, 60th, 67th, 70th, 80th and 90th percentile for various measurement bandwidths*

Δr = range resolution
B = measurement bandwidth
c = speed of light

Fig. 3 shows the variation in the bandwidth gain for different levels of accuracy. Beyond 4 GHz the bandwidth gain is less than 0.01 m/GHz for accuracy levels below 80%, while for 90% accuracy level, the bandwidth gain is less than 0.01 m/GHz beyond 4.2 GHz. This shows that bandwidth gain is negligible beyond 4 GHz and further increase in bandwidth will not yield further resolution gain.

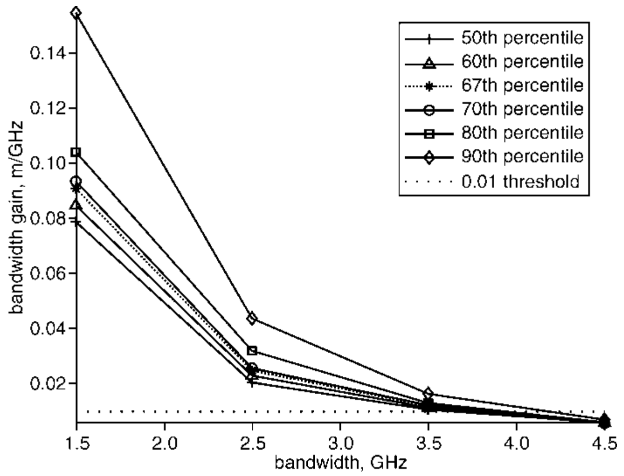

Fig. 3 *Bandwidth gains for various range estimation accuracy levels*

Conclusions: By the use of measurements it has been shown that 4 GHz, at 12.5 GHz, of bandwidth is enough for the accurate detection of the direct path in a typical indoor line-of-sight propagation environment, at the bandwidth gain threshold of 0.01 m/GHz. Employing extra bandwidth, just for locating a wireless device, will not yield significant benefit and will be a waste of resource. Furthermore, the bandwidth gain provides an effective figure of merit for deciding the receiver bandwidth requirements for accurate wireless device location estimation.

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