User Terminal Beam Steering System

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Abstract:

This publication describes a system directed at utilizing beam steering techniques on a user terminal to improve cellular performance between the user terminal and a base station. The user terminal uses a hybrid quadrature phase shifter network connected between two or more antennas and radio transceiver circuits to improve signal transmission and reception. The system may be configured to receive multiple-input multiple-output or single-input single-output channels from the base station.

Keywords:

Mobile device, User Equipment (UE), user terminal, cellular, cell tower, Base Station (BS), Base Transceiver Station (BTS), NB, eNB, gNB, 4G, 5G, New Radio (NR), 3GPP, radio bands, signal quality, signal strength, antenna array, beam steering, Sounding Reference Signal (SRS), hybrid quadrature phase shifter, aperture tuner, impedance tuner, antenna tuning, phase tuning, reception, transmission, Multiple-Input Multiple-Output (MIMO), Single-Input Single-Output (SISO), Time-Duplex-Division (TDD)

Background:

Each new generation of user terminals (e.g., mobile devices) comes with new and improved features (e.g., more sensors, additional components, larger displays). Designing a mobile device to fit these features into the same form factor and preserve core functionality continues to propose
a challenge to device manufacturers. A particular challenge is decreasing the physical footprint of antennas while maintaining cellular performance.

Additionally, with each new generation of 3GPP standards (e.g., 4G, 5G) the number of radio bands available for use by a mobile device grows exponentially. Mobile device manufacturers must consider these additional bands as they design the antenna systems. The growth of available radio bands, as well as the goal of optimal cellular signal quality, both necessitate better antenna systems.

Description:

This publication describes a system directed at utilizing beam steering techniques on a user terminal (“mobile device” or “device”) to improve cellular performance between the device and a base station (e.g., cell tower, Base Transceiver Station (BTS), NodeB (NB), evolved NodeB (eNB), next-generation NodeB (gNB)). The user terminal uses a hybrid quadrature phase shifter network connected between two or more antennas and radio transceiver circuits to improve signal transmission and reception. The system may be configured to receive multiple-input multiple-output or single-input single-output channels from the base station.

A user terminal includes at least one processor having logic for executing instructions, two or more radios (e.g., transceivers, transmitters, receivers), at least two or more antennas for signal transmission and reception, and a computer-readable medium (CRM). The CRM may include any suitable memory or storage device such as random-access memory (RAM), static RAM (SRAM), dynamic RAM (DRAM), non-volatile RAM (NVRAM), read-only memory (ROM), or Flash memory. The CRM includes a Beam-Steering Manager. The Beam-Steering Manager may be part of an operating system executing on the user terminal. In other aspects, the Beam-Steering
Manager may be a separate component (e.g., an application) executing within an application environment or “framework” provided by the operating system. The CRM also includes a tuning book, or configuration table, containing information for tuning the beam-steering circuit to a specific angle for optimally transmitting and receiving signal beams. The tuning book information may include frequency, beam angle, impedance settings, and phase delay settings for antenna-tuning circuits.

The user terminal performs operations under the direction of the Beam-Steering Manager to include beam sweeping, beam measurement, beam determination, and optionally, beam reporting. Beam sweeping describes covering a spatial area with a set of beams transmitted and received according to pre-specified intervals and directions. Beam measurement is the evaluation of the received signal strength at the base station or at the user terminal. Beam determination is the selection of the desirable beam at the user terminal antennas, based on the beam measurement operation. Beam reporting is an optional operation that sends beam quality and decision information from the user terminal to the base station, allowing the base station to control beam steering at the base station for a better link. These operations are repeated periodically to update the optimal transmitter and receiver beam pair over time.

In a Time-Duplex-Division (TDD) system including cellular telecommunications, given the reciprocity nature of an uplink channel and a downlink channel, beam sweeping may be achieved by monitoring the downlink signal (e.g., measuring the Received Signal Strength Indicator (RSSI)). Once a peak RSSI and an associated angle are found, this information may be used for uplink beam-steering and downlink beam reception. Additionally, the RSSI may be monitored by using a step function (e.g., 30 degrees per step) instead of a continuous sweep in
order to simplify the beam steering circuit design and reduce characterization effort. The peak RSSI for each relevant frequency and associated angles may be saved in the tuning book.

An example of a simple tuning circuit is illustrated in Figure 1. The diagram shows a 1x2 antenna array supporting two radios (e.g., two transmitters and two receivers, two transceivers). The radios support two bands added by the 5G NR (New Radio) 3GPP standard. In this example case, one radio is tuned to the n41 5G NR frequency band, and a second radio is tuned to the n77 5G NR frequency band.

![Figure 1](https://www.tdcommons.org/dpubs_series/3870)

The tuning circuit includes three impedance tuners (Impedance Tuner 1 (IT1), Impedance Tuner 2 (IT2), Impedance Tuner 3 (IT3)) that form a hybrid quadrature phase shifter network between the two antennas (Ant1, Ant2) and the radio transceiver circuits. This phase shifter network manipulates impedances and phase delays to form a beam at a certain angle. The impedance tuners may be configured, via the tuning book, to provide various impedances and various phase delays along the signal path. Two aperture tuners (Aperture Tuner 1 (AT1),
Aperture Tuner 2 (AT2) tune each antenna to a frequency. Components SP3T1 and SP3T2 are switches between the two radios and the tuning circuit. The switches are configured to switch between closing a transmission path, closing a receiver path, and closing a path providing a broadband impedance load ($Z_0$) to the tuning circuit. In Figure 1, the switches are positioned to close the transmission path, and the receiver path and broadband load are illustrated as open.

For n41 band and n77 band implementation, three different stages may be analyzed. The first stage establishes the frequency channel to be used and the optimal beam-steering angle for that channel. The second and third stages are the transmission stage and the receive stage. The n77 band implementation is identical to the n41 band implementation, but with the n77 components (SP3T2, ANT2, AT2, IT2) reversing roles with the n41 components (SP3T1, ANT1, AT1, IT1).

Using the n41 band implementation as an example, the first stage involves the operations of the Beam-Steering Manager. The Beam-Steering Manager performs a beam sweep by sending a Sounding Reference Signal (SRS) to a base station. SP3T1 is then switched to close the receiver path and SP3T2 is switched to $Z_0$. The Beam-Steering Manager obtains a beam measurement by measuring the RSSI of the return signal from the base station. The beam sweeping and beam measurement operations continue through all the beam-steering angles available in the tuning book. The beam determination is made by selecting the optimal beam-steering angle based on the best RSSI measured during this stage.

The second stage is the transmission stage. During this stage, the Beam-Steering Manager tunes the circuit to the best beam-steering angle determined in the first stage. ANT1 and ANT2 are set to the n41 frequency by AT1 and AT2, respectively. SP3T1 is switched to close the transmission path, and SP3T2 is switched to $Z_0$. IT1 and IT3 are configured with the impedances...
and phase delays to tune the optimal beam-steering angle. IT2 is set to high impedance on both terminals. The transmission signal of the radio tuned to the n41 band is propagated through both IT1 and IT3. The signal is transmitted from Ant0 and Ant1 as an optimally directed beam represented by the solid blue line in Figure 1.

The third stage is the receive stage. There are two configurations in this stage: the Multiple-Input Multiple-Output (MIMO) case and the Single-Input Single-Output (SISO) case. If the downlink channel is a MIMO channel, then IT3 is configured for high impedance on all four terminals, effectively presenting them as open circuits. ANT1 and ANT2 are configured independent of each other by AT1 and AT2, respectively. Both SP3T1 and SP3T2 are switched to close the receiver path, IT1 and IT2 are configured for pass-through, and the radios each receive an independent signal.

If the downlink channel is a SISO channel, then the tuning system is configured similar to the transmission stage. ANT1 and ANT2 are set to the single-input frequency by AT1 and AT2, respectively. SP3T1 is switched to close the receiver path, and SP3T2 is switched to $Z_0$. IT1 and IT3 are set to the relevant impedances and phase delays to receive a beam at an optimal angle. IT2 is set to high impedance on both ports. The radio tuned to the n41 band may then receive the single signal.

By implementing this system utilizing these beam steering techniques, the signal transmitted or received in a two-antenna system may achieve a 2 dB to 3 dB directivity gain over a single antenna system.