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Indoor positioning using WiFi or Bluetooth chirps and phased arrays

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ABSTRACT

This disclosure describes techniques for position location using WiFi or Bluetooth transceivers. In one implementation, the location of an object is triangulated using phased WiFi/Bluetooth arrays of narrow beamwidth and known locations. In another implementation, the digital frequency synthesis facility of WiFi or Bluetooth is leveraged to transmit a chirped radio-frequency signal to a target. The reflections of the chirp off the target, when mixed with the transmitted signal, give an estimate of target distance. Some applications of the described techniques include locating products in a supermarket, books in a library, objects in a home or office, etc.

KEYWORDS

- Indoor positioning
- Local positioning
- WiFi phased array
- Bluetooth phased array
- Chirp signal
- Radio beacon

BACKGROUND

The ability to accurately locate objects within indoor spaces has a wide variety of applications, e.g., in warehousing, in retailing, in homes and offices, etc. Indoor positioning is not widely available due to the size of the equipment needed. For example, ultrasound positioning requires large antennas to range objects accurately; alternately, if better resolution is sought via the use of higher frequency ultrasound, a correspondingly higher amount of power is needed to overcome the greater attenuation at higher frequencies. Similar considerations apply to millimeter radio waves.

With the advent of internet-of-things technology, WiFi/Bluetooth radio transceivers and sensors are available in sizes small enough to be fitted to objects or products typically found in a warehouse or retail space. However, these are used to estimate distances based upon received signal strength indicator (RSSI), which is subject to multi-path and interference, and is not very accurate.

DESCRIPTION

WiFi or Bluetooth phased arrays

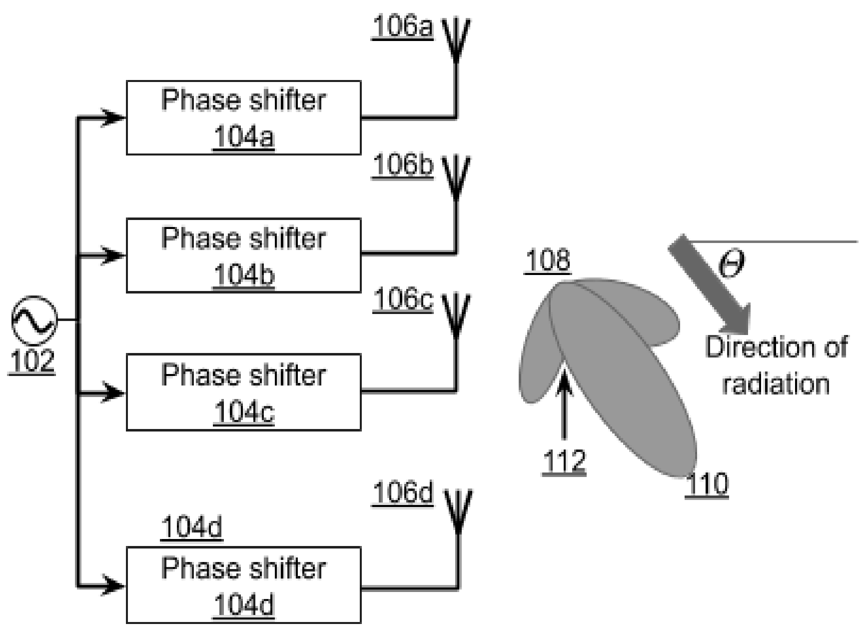

Fig. 1: WiFi or Bluetooth phased array

Fig. 1 illustrates an example WiFi or Bluetooth phased array, which directs radio energy in a sharp yet steerable direction. A WiFi or Bluetooth transmitter (102) generates a signal that is fed to several antenna elements (106a-d) via phase shifters (104a-d). Radio waves that propagate out from the antenna elements form an interference pattern in space (108) due to their differing phases. The interference pattern is characterized by a beam maximum (110), which is the direction of maximum radio energy density, and several minima, or beam nulls (112), which are directions of minimal radio energy density. The direction of the beam maximum can be steered dynamically by modifying the radio signal phases using the phase shifters. In this manner, a narrow beam of WiFi or Bluetooth radio energy can be created at any design direction. In a similar manner, a phased array of antennas can be designed to have greater receive sensitivity in a design direction.

Use of WiFi or Bluetooth phased arrays to locate objects

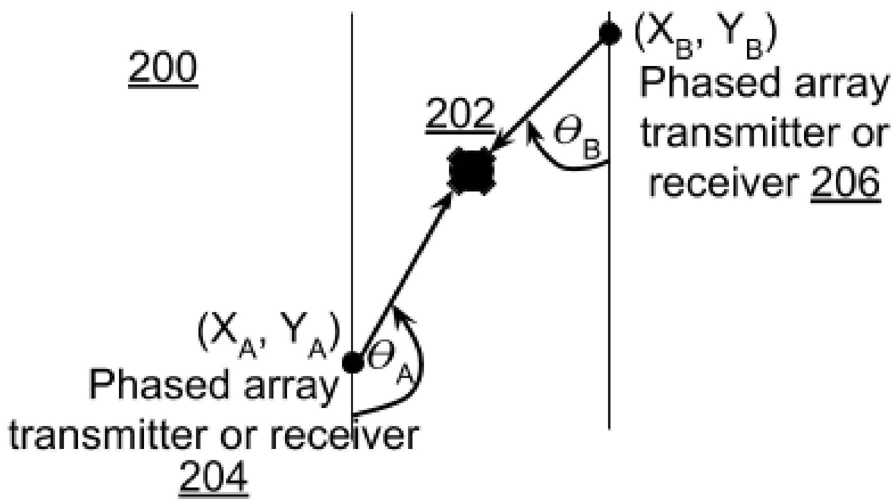

Fig. 2: WiFi or Bluetooth phased arrays to locate objects

Fig. 2 illustrates the use of WiFi or Bluetooth arrays to locate objects, per techniques of this disclosure. One or more phased arrays (204, 206) with known coordinates (X_A, Y_A), (X_B, Y_B), etc. are located in a region (200), e.g., the interior of a warehouse, a retail outlet, etc. An object (202) that is to be located emits radio waves, e.g., in an omni-directional pattern. The phased arrays use their narrow beamwidths to identify the direction of the radiation, e.g., the phased array at (X_A, Y_A) determines that the radiation arrives at the angle $\boldsymbol{\theta}_A$ to a grid line, and the phased array at (X_B, Y_B) determines that the radiation arrives at the angle $\boldsymbol{\theta}_B$ to the grid line.

The object is thereby located at the intersection of the line originating at (X_A, Y_A) at an angle θ_A and the line originating at (X_B, Y_B) at an angle θ_B.

Conversely, the object to be located (202) can serve as a passive receptor of radiation, while the phased arrays (204, 206) can serve as transmitters of narrow beamwidth WiFi or Bluetooth radiation. As the phased arrays scan space, they transmit the angular direction of their beam maxima. The object to be located receives each beam maximum and demodulates the angular direction therein. From the observed angular directions of the phased arrays relative to the object, the object performs triangulation calculations to locate itself. In this mode, the phased arrays act in a manner similar to sharply-directed rotating beacons.

<u>WiFi chirps</u>

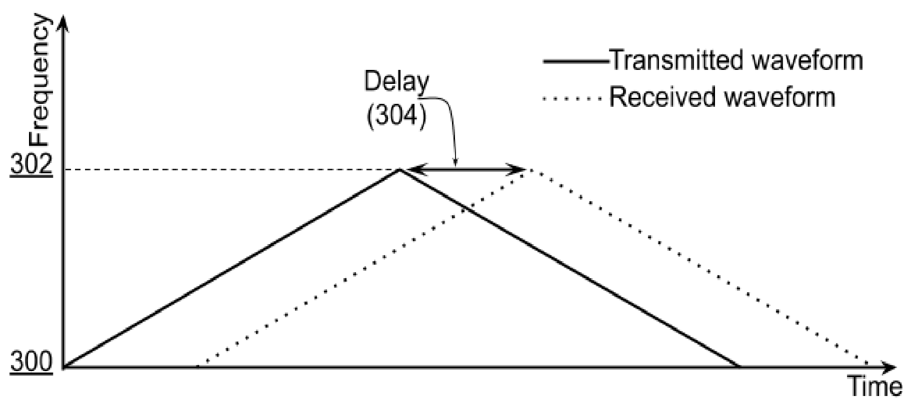

Fig. 3: A chirp signal

A chirp is a signal whose frequency changes with time, e.g., in a linear, exponential, or other manner. Fig. 3 illustrates a chirp whose frequency resembles a triangular wave, e.g., its frequency starts at a nominal frequency (300), increases linearly until it reaches a maximum (302), then decreases linearly back to the nominal frequency. Such a chirped wave is transmitted (solid line) and received, on being reflected off a target (dotted line), after a delay (304). The frequency offset between the transmitted and received waves is proportional to the delay. For example, when the transmitted and received waves are multiplied together (mixed), the delay appears as a spectral peak in the mixed waveform. In this manner, delay, e.g., distance between transmitter and target, can be estimated by calculating the Fourier transform of the mixed waveform.

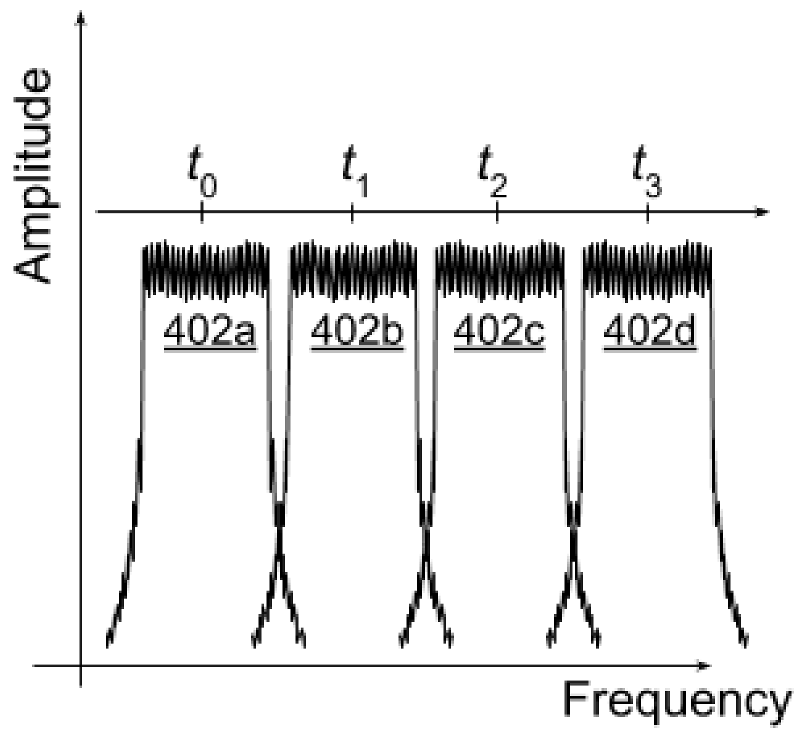

Fig. 4: Generating a chirped WiFi signal

Fig. 4 illustrates generating a chirped signal using orthogonal frequency division multiplexing (OFDM). In OFDM, tones are generated digitally using fast Fourier transforms. An initial waveform comprising a set of tones (402a) is produced at a time instant t_0, and at successive time instants t_1, t_2, t_3, etc., the tones are shifted in frequency to produce frequency-shifted spectra 402b-d. In this manner, a chirped signal can be produced using the OFDM mode of WiFi.

Use of WiFi or Bluetooth chirps to locate objects

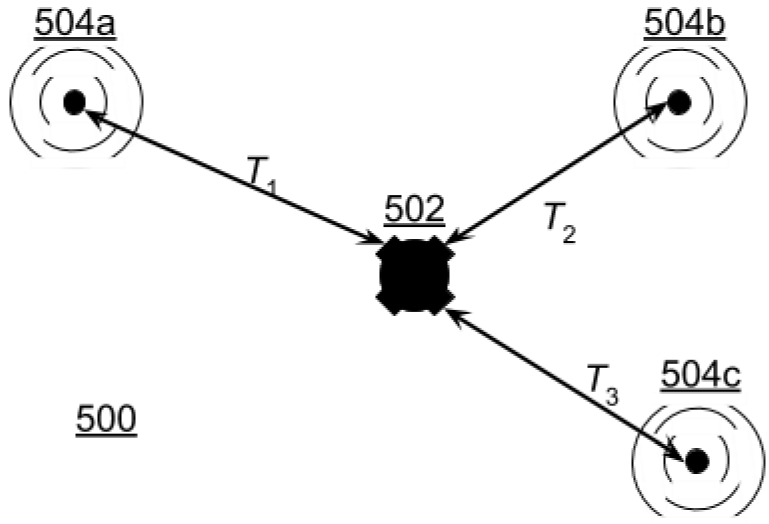

Fig. 5: Object location using WiFi or Bluetooth chirps

Fig. 5 illustrates locating a target object (502) using WiFi or Bluetooth chirps. WiFi or Bluetooth transmitters (504a-c) located at known locations within an indoor space (500) estimate distances to the target object by transmitting chirp signals and performing spectral analysis of the reflected signals, as explained above. The measured distances are used in concert with the known transmitter locations to triangulate the location of the object.

Alternately, the target object (502) can transmit a chirped signal that reflects off reflectors (504a-c) located at known locations within the indoor space. The target object can thereby estimate distances to the reflectors and locate itself using triangulation.

Further to the aforementioned techniques, a combination of phased arrays and chirped signals can be used to locate objects within indoor spaces. For example, RSSI, angle of wavefront, frequency offset of chirp signal, etc. can be used in a combined manner to locate objects.

CONCLUSION

This disclosure describes techniques for position location using WiFi or Bluetooth transceivers. In one implementation, the location of an object is triangulated using phased WiFi/Bluetooth arrays of narrow beamwidth and known locations. In another implementation, the digital frequency synthesis facility of WiFi or Bluetooth is leveraged to transmit a chirped radio-frequency signal to a target. The reflections of the chirp off the target, when mixed with the transmitted signal, give an estimate of target distance. Some applications of the described techniques include locating products in a supermarket, books in a library, objects in a home or office, etc.