Literature Review

**Indoor Localization**

Indoor localisation technologies are a widely researched topic in recent years, with a focus on developing a method on widescale deployment. With the growing availability of advanced mobile devices and wireless infrastructure in public areas, accurate indoor localisation systems within places such as hospitals, shopping centres, warehousing etc. is more feasible than ever. Being able to pinpoint the location of a wireless devices requires higher location resolution for indoor environments than in outdoor applications {~1~}. Although global positioning system (GPS) works extremely well for an open-air localization, it does not perform effectively in indoor environments due to the disability of GPS signals to penetrate in-building materials {~3~}.   
  
{~32~} All these approaches require site survey over areas of interests to build fingerprint database. The considerable manual cost and efforts, in addition to the inflexibility to environment dynamics are the main drawbacks of fingerprint-based methods.  
{~16~} Ultrasound seems an obvious technology for localization since ultrasound and distance measurement have quite a history, e.g. ultrasound parking assist with airborne ultrasound also with 40 kHz. In [4], [5] the ultrasound senders modulate the data by binary shift keying (BSK). However, to overcome the multipath propagation, they use ultrasound pulse lengths of up to 100 ms [6], [7] and code division multiplex access (CDMA) codes (e.g. Kasami code and Barker code).   
{~28~} If too many ultrasonic signals are blocked by the obstacles in the environment, it is easy for a listener to receive less than 3 ultrasonic signals such that this listener can no longer be localizable  
{~12~} Wireless infrastructure that is currently used for both indoor and outdoor localisation, tends to be computationally intensive with high power consumption. Wireless sensor networks are an alternative form of wireless infrastructure that can be used for localisation but also operate at low power. Wireless sensor networks are used for a sensing and actuation applications including smart metering. As energy usage monitoring becomes an important lifestyle factor for workplaces and households, wireless smart metering networks will be more widely used. Wireless smart meters are being incorporated into new buildings for climate control and to improve power usage eﬃciency. Wireless smart metering infrastructure can potentially be used for low-powered indoor and outdoor localisation.

**Implementation Issues - sync**   
{~27~} There are several requirements for localization techniques, including accuracy, robustness, and ease of deployment.  
{~1~} if a positioning technique makes use of a Bluetooth signal, it can be only practical under a few square meters   
{~4~} In order to achieve stable reception of ultrasonic waves, it is considered necessary to use a broadband transducer [9] and a signal processing technique such as modulation of the ultrasonic waves.   
{~9~} The beacons become active in a time-triggered fashion, both for simplicity, and for avoiding collisions (see Sect. 5). The timely properties of the radio channel are well known in our setup, as we use low-power RF modems  
{~9~} we brieﬂy discussed the problem of improving the position update rate by coordinating beacons and by using orthogonal sequences that allow the ultrasound signals to be sent completely concurrently. The second method turned out to be feasible only with a high computational overhead and also, because the length of the sequences, the beneﬁts are questionable.   
{~10~} If the receiver clock is not in synchronism with the infrastructure and t0 is not known, the TOF cannot be measured directly. However, in order to overcome this difficulty without turning over to Time Difference Of Flight (TDOF) it is possible to set an initial upper bound of t0 and perform “pseudo-range” calculations that will consequently result in distance overestimations with equal offset. Then, the circles intersection area may be minimised through local search and t0 may be found. It is also possible to ease the process by transmitting timing information within the signal that will help in reducing the solutions space.   
{~16~} We present an ultrasound transmission system for TDOA localization, which is optimized for an infrastructure with low power and cost-effective stationary senders. Therefore, our pulse modulation system achieves the same performance as analog sine generation. It combines three key features: for energy efﬁciency the signal is generated by a microcontroller with a pulse modulation, we use narrow band piezo-electric transceivers to band pass the pulse modulated signal, and the signal is modulated by π/4-DQPSK to achieve high data rate for pure LOS communication and correct localization. With the shown precision of the frame synchronization the distance error corresponding to the transmission delay is smaller than 3.7µm. Moreover, the low power design enables feasible indoor photovoltaic power supply and reduced installation costs.

**Methodology**  
{~4~} There is no system that can be used for all applications under all environmental conditions. From the point of view of usability and localization accuracy, it is preferable to use a system that performs localization by TOA (Time of Arrival) or TDOA (Time Difference of Arrival) using the propagation delay time of electromagnetic waves, based on a principle similar to that used in GPS.  
{~2~} The most common techniques used in the literature are based on the TDOA. This technique uses two different transmission media, where the fast transmission medium (generally radio communication) is used as a synchronization between devices and a slower transmission medium (e.g., ultrasound) is used for distance ranging.   
{~9~} Distance is measured using the difference in time-of-ﬂight of RF signals and ultrasound signals. The time difference for travelling a distance d between the ultrasound signal and the radio signal is. For a distance d of 10 m, the radio signal needs about trf 30 ns. The ultrasound signal, however, will need about tuf 30 ms. As trf << tus, trf can safely be omitted from the above term. Unfortunately, the speed of sound is not constant. Indoors it varies mainly with temperature. Between –20 and 40 C, it can be approximated in a linear fashion: vultrasound = (331.6 + 0.6T)m/s where T is in C. Not dealing with temperature would introduce rather large errors, e.g. 3.4% or 0.34 m when measuring a distance of 10 m and going from 10 to 30 C. There are two possibilities for dealing with unknown speed of sound: (1) try to approximate the speed of sound using sensors, e.g. temperature sensors, and (2) using one more beacon, and introduce it as another unknown variable in the positioning calculations  
{~4~} The ultrasonic waves from a small mobile device with an ultrasonic transmitter are received by the receiver array. The ultrasonic receiver array and the mobile device are synchronized by a wireless connection. The time required for an ultrasonic pulse transmitted from the mobile device to arrive at each ultrasonic receiver (propagation delay time) is measured. By multiplying the measured propagation delay time by the speed of sound, the distance between the mobile device and each of the ultrasonic receivers is derived. Since the locations of the individual receivers are accurately given beforehand, the location of the mobile device can be derived three-dimensionally by solving a set of simultaneous equations involving the measured distance to each receiver and the locations of the receivers.   
{~3~} WiFi-based indoor localization has been attractive due to its open access and low-cost properties. However, the distance estimation based on received signal strength indicator (RSSI) is easily affected by the temporal and spatial variance due to the multipath effect, which contributes to most of the estimation errors in current systems.   
{~3~} we observe that RSSI is roughly measured and easily affected by the multipath effect which is unreliable  
{~3~} We argue that a reliable metric provided by commercial NICs to improve the accuracy of indoor localization is in need. Such metric should be more temporal stable and provide the capability to benefit from the multipath effect. In current widely used orthogonal frequency division multiplexing (OFDM) systems, where data are modulated on multiple subcarriers in different frequencies and transmitted simultaneously, we have a value that estimates the channel in each subcarrier called channel state information (CSI). Different from RSSI, CSI is a fine-grained value from the PHY layer which describes the amplitude and phase on each subcarrier in the frequency domain.  
{~4~} In this paper, the design of a fully distributed localization system based on ultrasound, mainly for the indoor environment, is described. This system performs localization with as few positioning references as possible by an iterative technique. When such a localization method is used, deterioration of localization accuracy due to no line-of-sight signals and to accumulated errors is a problem.   
{~9~} These are modulated using binary phase shift keying (BPSK). BPSK matches the computational abilities of our beacons and achieves a good coding efﬁciency of 1 baud Hz–1 of bandwidth. For our ultrasound transducers, this yields a maximum data rate of about 2,000 chips per second (as we have a usable bandwidth of about 2 kHz).   
{~10~} Using v to represent the speed of sound together with the time of Time-Of-Flight (TOF), the distance d can be calculated:

d¼TOF v: ð5Þ To find the distance d in Equation (5) the TOF of each vector between one of the anchors and the mobile device is measured through its TOA by finding the peak of a correlation result w"  
{~16~} Holms et al. present in [9] for an indoor positioning system ultrasound communication with frequency shift keying (FSK) modulating the sender identiﬁer (ID). Chirp spread spectrum (CSS) modulation with broadband ultrasound transceivers is also used for localization (e.g. [10]) to improve the precision of TOA measurements for multipath channels. For ultrasound narrowband transceivers, we developed a CSS and FSK combined modulation scheme [11]. Nevertheless, the system also uses multipath propagation.   
{~20~} The performance of the localisation can be evaluated using Cramer–Rao lower bound (CRLB) [8, 10– 14]. CRLB is a theoretical lower bound of the variance of the position estimations and shows the smallest positioning error that can be achieved. It is defined as the inverse of the Fisher information matrix (FIM) [10]. In [8], CRLB for 46 IET Sci. Meas. Technol., 2011, Vol. 5, Iss. 2, pp. 46–53 & The Institution of Engineering and Technology 2011 doi: 10.1049/iet-smt.2010.0051 www.ietdl.org line-of-sight (LOS) TDOA localisation has been derived and compared with the achievable accuracy of various position localisation algorithms.   
{~26~} The reason why we choose TDOA instead of RTT/TOA is to lower the system complexity and achieve high measurement accuracy. Although RTT/TOA requires no synchronization and does not manipulate the measured distances, extra ﬁlter, wireless communication elements, and additional receiver transducer have to be added to the MS since the system needs to receive the ultrasonic signal or transmit a timestamp. Thus, the weight and the size of the system increase and power consumption becomes higher due to the nonexisting sleep modes.   
{~30~} RSSI [1,2] uses the signal strength of radio communication to estimate the distance between devices. The AoA [3,4] technique uses an array of receivers to evaluate the incoming reception angle. Calculating the location of the source is done by combining the angles of different receivers. In ToA [5], nodes try to estimate distances by evaluating the round trip time of a message and its reply. TDoA uses a radio synchronization packet followed by an ultrasonic pulse. The distance between nodes is calculated by the travel time of the ultrasound signal. This last method also offers the highest level of accuracy for indoor localization [6].   
{~30~} Within TDoA, two ultrasound ranging categories have been proposed. The first approach consists of sending a simple narrowband pulse, which is also known as the impulsive technique. A second approach consists of spreading the signal using orthogonal codes. Direct sequence and frequency hopping spread spectrum signals have previously been introduced in ultrasound ranging techniques [7,8]. The frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS) offer the advantage of being more noise resistant compared to non-spread spectrum techniques. Both methods have their own (dis)advantages [9]. DSSS uses a signal carrier on which an orthogonal spreading code is modulated together with the data. This results in a signal being spread around the carrier. By contrast, the FHSS method uses a carrier that switches between a given set of frequencies. The followed frequency pattern depends an a given orthogonal code. The former method is likely to be more resistant to white noise, while the latter method is more resistant to in-band noise.   
{~30~} The accuracy level of the measurements of narrowband [14] systems is generally about a few centimeters. With the incremental approach, the accuracy drops to about 15 cm [13]. The advantage of these systems is the simple ultrasonic interface and low computational needs. However, the narrowband ultrasonic pulses are vulnerable to noise, and only one sender is allowed to send a pulse in a given time slot. With the wideband approaches, these problems can be alleviated. Existing systems using this technique are able to achieve sub-centimeter accuracies, but with a higher processing power cost  
{~32~} A large body of indoor localization approaches adopt fingerprint matching as the basic scheme of location determination. The main idea is to fingerprint the surrounding signatures at every location in the areas of interests and then build a fingerprint database. The location is then estimated by mapping the measured fingerprints against the database. Researchers have striven to exploit different signatures of the existing devices or reduce the mapping effort. Most of these techniques utilize the RF signals.   
{~32~} Model-based techniques. Another type of localization approaches use geometrical models to figure out locations. In those methods, locations are calculated rather than searched from known reference data. For example, the log-distance path loss (LDPL) model is used to estimate RF propagation distances according to the measured RSS values. These approaches trade the measurement efforts at the cost of decreasing localization accuracy due to the irregular signal propagation in indoor environment.

**Existing methods**   
{~1~} Ultrasonic [Fischer et al. 2008] is a well-known ideal candidate for indoor positioning that relies on the TOA scheme. The key idea is to use an ultrasonic transceiver to emit and detect ultrasonic signals. While recording the signal traveling time between a pair of transmitter and receiver, it is possible to compute their separating distance given the medium traveling speed. In general, ultrasonic wave emission is usually directional, which introduces difﬁculties in orienting the transceiver precisely. The early Cricket system [Priyantha et al. 2000] utilizes the difference in propagation speeds and estimates the distance via coupled RF and ultrasonic signals. Although Cricket exhibits high accuracy (i.e., 6cm) as well as privacy protection, it suffers from the inherent narrowband disadvantage. Instead, Hazas and Hopper [2006] explore the usage of broadband ultrasonic that has superior characteristics over the narrowband counterpart. Such a broadband ultrasonic system is deployed using Dolphin units and the ranging performance is 2cm. Itagaki et al. [2012] develop a moving object tracking method based on spread spectrum ultrasonic (Figure 13). To handle the Doppler effect brought by moving targets, a tracking method by limiting correlation calculation in a deﬁned range is proposed.  
{~2~} The ultrasound signals are composed of FSK-modulated signals, where the carrier frequency sequences are speciﬁed by orthogonal Gold codes.   
{~7~} These localization systems function by comparing WiFi received signal strength indicator (RSSI) and a pre-established location-speciﬁc ﬁngerprint map. However, due to the time-variant wireless signal strength, the RSSI ﬁngerprint map needs to be calibrated periodically, incurring high labor and time costs. In addition, biased RSSI measurements across devices along with transmission power control techniques of WiFi routers further undermine the ﬁdelity of existing ﬁngerprint-based localization systems  
{~9~} By encoding and modulating the ultrasound pulses, we are able to achieve greater accuracy in distance measurements. Besides improving the distance measurements, we improve the position update rate by synchronising the active beacons.   
{~9~} The principle of operation is based on distance measurements to at least three beacons and subsequent trilateration. The distance is determined by the differences between the time which a radio signal and an ultrasound signal need to travel from a beacon to the respective receivers on the mobile entity  
{~9~} As in any other system utilising both radio and ultrasound signals, corresponding radio und ultrasound signals must be correlated at the receiver. Cricket does not modulate the ultrasound signal, so it needed a different mechanism: typically, radio signals can be received at much greater distances than ultrasound signals. This ensures that whenever an ultrasound signal is received, so is the radio signal. Using a small bandwidth radio link, and having long enough radio messages, it is assured that the ultrasound signals arrive while the radio message is still being transmitted. In the absence of interference, this ensures that the correct correlation of radio and ultrasound signal is done. Errors in measurement due to changes in the speed of sound, e.g. due to temperature, are irrelevant because only the closest beacon is used to determine the current position.   
{~9~} We were able to improve the system by discarding the analogue tone decoder. Instead, we fed the ampliﬁed input signal to a comparator circuit. The output is a binary signal that was directly fed into a microcontroller’s capture unit. Tone detection was done in software [14]. We recently became aware that Cricket changed to the same technique [13, 15]. The results were promising for aligned ultrasound transmitters/receivers: all measurements were within ±2 cm of the actual distance.   
{~10~} Gold codes are a suitable example of a PN for this purpose as the cross-correlation between codes is low. Gold codes are useful since a large number of codes can be generated with good auto-correlation and cross-correlation properties(Boneyetal.,1996), which will be necessary to allow identification of each one of a set of anchors. Each data package is therefore identified by its code that spreads the data. Once the transmission information is set in 24-bit Golay code words, Direct Sequence-Code Division Multiple Access (DS-CDMA) may be used to transmit the unique wide band coded signal using a modulation scheme such as Binary Phase-Shift Keying (BPSK).   
{~21~} The bandwidth of UWB signals is of the order of several gigahertzs, which corresponds to sub-nanosecond time resolution. As a result of the fine time resolution, UWB transmissions are well suited for precise positioning using time domain techniques. The characteristic of short pulse duration allows the receiver to differentiate and resolve the different multipath components of the arrival signals. This provides robustness against multipath fading and it makes UWB particularly attractive for indoor position localisation [3 –5]. In addition, the wide bandwidth of the UWB signals results in very low-power spectral densities, which reduces interference on other radio-frequency (RF) systems  
 {~27~} Our proposed algorithm can estimate DOA and delay values simultaneously in an entirely different manner from the existing approaches. The procedure of the TSaT-MUSIC algorithm is as follows. First, sets of DOA and delay values are estimated using the S-MUSIC and T-MUSIC algorithms, respectively. Next, the true pairs of DOA and delay values are decided by applying the TMUSIC algorithm at a sensor different from the sensor used in the first step. As a result, we can estimate DOAs and delays with only t  
{~29~} In this work, we prove this theory to be right by means of a direct comparison with the TOA multilateration technique as well as our proposed technique. However, and much more significantly, in this work, we build up on the fundamental working principles of the TSOA-based multilateration technique and use it to derive a novel technique which we coin as time reflection of arrival (TROA). We derive a theoretical lower bound on the covariance of the TROA estimator based on the Cramér–Rao lower bound (CRLB), and show that our proposed approach achieves relatively good operational performances when the mean squared error (MSE) implications are considered.

{~31~} In the proposed approach, the wearable devices embedded into person are used to realise their displacement vectors, thus estimating their own locations. In addition, a walking prediction mechanism that predicts the moving direction of nodes is proposed to increase localisation accuracy. WILA is a scalable, practical and efficient localisation approach for IoT in mobile environments.   
{~32~} By exploiting user motions from mobile phones, we successfully remove the site survey process of traditional approaches, while achieving competitive localization accuracy. The rationale behind WILL is that human motions can be applied to connect previously independent radio signatures under certain semantics. WILL requires no prior knowledge of AP locations, and users are not required for explicit participation to label measured data with corresponding locations, even in the training phase. In all, such features introduce new prospective techniques for indoor localization  
{~32~} Other than the RSS related model, other geometric models are also exploited for characterizing the relationship of signal transmitters and receivers. These systems include PinPoint [19] based on Time of Arrival (ToA), Cricket [20] based on Time Difference of Arrival (TDoA), and VOR [21] based on Angle of Arrival (AoA). Model-based techniques usually require the placement of additional infrastructure, modifications of off-the-shelf products, or knowledge of hardware configuration  
{~12~} We found that using only received signal strength or other wireless channel propagation properties was not suitable for tracking users in real time, due to the lengthy time taken to calibrate for channel propagation parameters.

**Deployment**  
{~1~} The main hurdle is the deployment cost. Out of the 22 solutions, the average setting and calibration time is 5 hours for two rooms covering 300 square meters. This may be unrealistic and intrusive when deploying these localization systems in large deployment sites like shopping malls. {~4~} in which indoor localization is realized with as few initial references as possible, based on the idea of iterative multilateration  
{~9~} This is done using ﬁve ultrasound receivers in a V-shape, and measuring phase differences in the incoming ultrasound signal. With Cricket Compass, positioning in terms of absolute coordinates within a room was introduced. This requires at least four beacons. The method described in [4] overcomes the problem of not knowing the speed of sound, so no further sensory equipment is needed.   
{~20~} Based on the analysis and experiments, it has been investigated how the number of anchor nodes and the geometry of the network affect the positioning accuracy.   
{~20~} The localisation accuracy depends mainly on four factors: (i) Accuracy of the range measurements: The range measurements used for the position estimations can be corrupted by multipath or non-line-of-sight (NLOS), which cause the range estimations to be noisy or biased. The localisation performance can be severely degraded by poor range measurements. (ii) Location errors of the anchor nodes: As mentioned earlier, the time resolution of UWB ranging is in sub-nanosecond, and the corresponding range measurements are on the order of centimetres. If the locations of anchor nodes are not accurate enough, the location errors of the anchor nodes may become a dominant source of positioning error. Therefore, the precision of the locations of the anchor nodes also play an important role in UWB localisation system. (iii) Geometric configuration of the system: Geometric configuration refers how the anchor nodes are placed relative to the blind nodes, which will be investigated in details in the following sections. (iv) Positioning algorithm used to estimate the location of a blind node: Without a robust positioning algorithm, the blind node may not be successfully localised in indoor environment. There also exist trade-offs among the positioning accuracy, computational complexity, cost and power consumption. In this paper, we focus on the effects induced by the ranging accuracy and the geometric configuration, and thus it is assumed that the anchor nodes are perfectly placed, and one positioning algorithm is used to determine the locations of the blind nodes.   
{~22~} Distribute & Erase can replace the hard, time-consuming, and fault-prone manual calibration. Furthermore, it also operates distributed, autonomously, and without further hardware or special a priori knowledge. Therefore, D&E is suitable for the fast, cheap, and easy calibration of localization systems during deployment. As D&E calibrates progressively, it is also suitable for recalibration, especially after changes of the infrastructure.   
{~22~} A common problem of anchor based localization systems is the determination of the anchors’ positions. A manual calibration is time consuming, since each anchor has to be measured individually, and fault-prone, because of inaccurate measurement methods and human error  
{~26~} Furthermore, we implemented a WLAN communication for synchronizing the receivers and therefore reducing the installation effort.   
{~26~} A conventional ultrasonic transmitter is limited by the beam width. Ming et al. [22] presented a combination of two ultrasonic transducers to increase the beam width (factor 2) so that the coverage of the ultrasound localization system becomes wider . We developed a 2-D isotropic ultrasound transmitter with a beam width of 360°, which is shown in Fig. 5. The block diagram of the transmitter is given in Fig. 6. An MSP430 microcontroller generates 1-ms impulse per 300 ms with an ultrasound frequency of 40 kHz. For each ultrasound transducer, an ampliﬁer is used to amplify the impulses to extend the transmitting distance. The isotropic transmitter consists of an array of eight ultrasound transducers placed in a round body. The angle of aperture of one transducer is 45°. By using eight ultrasound transducers, the coverage range can be increased by a factor of 8. The 360° radiation pattern of our transmitter in the x–y plane is shown in Fig. 7.   
{~28~} In an indoor environment, beacons are deployed incrementally on the ceiling in order to localize the listeners in between the ceiling and the floor. We first propose a water-drop shaped radio model for the beacon to replace commonly assumed spherical radio model in order to provide true coverage of the listeners. Obstacles in the indoor environment are then considered to take into account the line-of-sight restrictions and thus to enable practical beacon deployment. Although when taking into these two considerations, the number of deployed beacons required tends to be high, it would otherwise be impossible to provide true coverage of the listeners in the indoor environment utilizing ultrasound-based localization.   
{~28~} Though RF is the more popular media for localization in indoor environments, its localization precision is usually poor. Ultrasound can provide higher localization precision. It, however, suffers from the line-of-sight restrictions. Beacon placement thus becomes challenging for ultrasound-based indoor localization in environments with various obstacles such as desks and chairs  
{~28~} A beacon on the ceiling can simultaneously transmit RF and ultrasound signals to the listener as in [5]. Since the transmitted RF signal propagates at the speed of light in the air (≈ 3×108 m/s), it arrives almost immediately at the listener. The transmitted ultrasound signal will arrive at the listener much later since it has to propagate in the air at the speed of sound (≈ 346 m/s with a temperature of 25°C in dry air). The time difference of the arrival times for the transmitted RF and ultrasound signals is thus approximately equal to the propagation time of the transmitted ultrasound signal. The listener can then derive the distance from the beacon by multiplying the ultrasound propagation time by the speed of sound. Since the location of the beacon is known when the beacon was deployed, the listener must be located at the surface of a sphere that is centered at the beacon and with a radius of the derived distance from the beacon to the listener.  
{~28~} In 3D, the actual position of the listener can be derived with distances from at least four beacons. However since the listener can only be located below the ceiling, distances from three beacons would be sufficient to calculate the listener’s location.  
{~28~} By the results of our field measurement, we have observed that the ultrasound transmission is highly directional as shown in Figure 7. Only when the listener is inside the water-drop shaped area enclosed by the solid line can the listener derive distance measurement value from the beacon.   
{~28~} Using a realistic radio model, we discover that (1) more beacons are needed to provide full coverage of the listeners since the covering space of an ultrasound transmitter is smaller than a perfect sphere and (2) the number of required beacons grows linearly with the size of the space. Taking into consideration of the obstacles, we find that (1) many more beacons are needed to localize the listeners since the ultrasound signals can be blocked by the obstacles in the environment, (2) the requirement of beacons grows about inversely proportionally with the height of the listeners since when the listener is higher the less effect the obstacles will have to block the ultrasound signal from beacons, and (3) the placement of the obstacles have significant impact on the beacon deployment especially when the listener is lower.   
{~30~} In the Cricket [10] and the Bat [11] systems, nodes use the time of flight of a narrowband ultrasonic pulse to calculate their position. The topology of these systems is composed of fixed nodes or beacons and mobile nodes, where the mobile nodes try to calculate their position based on the fixed nodes. These systems offer a high level of accuracy. However, the disadvantage is the considerable amount of fixed position nodes needed, which increases the setup cost.