CONCEPTUAL DESIGN OF CENTIMETER ACCURACY LOCAL POSITIONING SYSTEM

Venu Annamraju and Kurt Kosbar
Department of Electrical and Computer Engineering
University of Missouri – Rolla
Rolla, MO 65409-0040

ABSTRACT

This project investigates the feasibility of position detection in an office or industrial setting. The objective is to design a low-cost positioning system that uses the unlicensed 5.7 GHz ISM band, with centimeter accuracy and limited range. During the conceptual design phase of the system, indoor channel models will be investigated to determine which of a variety of architectures will be useful. For triangulating the position, an array of widely spaced stationary receivers and a mobile transmitter is proposed.

KEYWORDS

RF methods, Position Location, Indoor Channel, 5.7 GHz, ISM.

INTRODUCTION

Position location in the outdoor channel is often performed by Global Positioning System (GPS) receivers. Differential and kinematic GPS can typically achieve sub-meter accuracy. The GPS is ineffective in many indoor environments due to severe multipath interference and path loss. Traditional GPS receivers use signals from a minimum of four satellites to triangulate their position. The receivers depend on clear line-of-sight (LOS) for their operation. Their performance degrades under non-LOS and multipath environments.

Position location systems have slightly different objectives than telecommunication links such as HiperLAN (5.2GHz in the U-NII band). Channel models suitable for communication links may not accurately address the problems of position location systems. In geolocation applications the relative power and time of arrival (TOA) of the signal via the (LOS) path are important [1].

A conceptual design for a low cost position location system for use in an office or small factory setup is presented in this paper. The proposed scheme has many receivers at known location in an office and a mobile transmitter. Alternate approaches to the problem making use of Ultra-Wide band CDMA [2] and multi-sensor fusion [3] are also considered. Prior to deciding upon any one design, it is useful to have an insight of the channel models that are used. A detailed description of the various channel models for the indoor channel is given in [4].

The data from the receivers may be used in various ways depending on the algorithm. The parameters useful for position location are amplitude, phase shift, time delay and frequency shift.
Some of the techniques employed are triangulation, azimuth/elevation, circulation, range difference and differential Doppler. Many combinations of the above techniques may be utilized and they are called mixed mode location techniques. Alternately, acoustic sensors could be used in conjunction with the RF system. The data from both the sensors is fused in a way to obtain accurate results.

CHANNEL MODELS

Some of the recent statistical models proposed by Saleh and Valenzuela [5], Hashemi [6], Keenen and Motley [7], and Rappaport et al [8]. provide an insight to the path loss, received amplitudes and arrival times of the multipath components. The primary concern is the RMS delay spread, which is crucial to the transmission rate and the Bit-Error Rate (BER). The models have been built around extensive measurement results. While some models worked in office environments, they could not be successfully applied elsewhere.The Rayleigh, Weibull, Nakagami-M, Lognormal and Suzuki distributions [4] are considered as potential models for the path amplitudes. The arrival times of paths is modeled by a Poisson distribution, on the premise of randomly located scatterers. In a typical office environment, the scatterers are not entirely random, owing to cabinets, tables etc. To account for deviations from the standard Poisson model, a modified Poisson model was proposed [4]. Classification of indoor environments into LOS, Obstructed LOS (OLOS) and Non LOS (NLOS) are made according to the main propagation characteristics between transmitter (TX) and receiver (RX) [17]. For LOS and NLOS environments, the lognormal distribution of amplitudes and the Poisson model fit the measured data significantly better than the Rayleigh or Rician models [3, 10].

In LOS environments, a GPS type receiver is capable of detecting the highest amplitude LOS component and determines the TOA with minimal error. The performance degrades in NLOS environments. The error in distance is proportional to the difference in the TOA of strongest path detected and the TOA of the LOS component. In this situation a RAKE receiver performs better in resolving the multipath component and makes intelligent guess on the TOA of the LOS path. None these work well for the OLOS environments. The channel structure can change due to human shadowing [9] or movement of equipment. Channel modeling will be used to correlate the TX-RX positions to the statistics obtained. This would be useful to differentiate the profiles obtained by TX movement from changes in channel structure due to other reasons. Depending on the position changes in TX-RX, the profiles can be analyzed as small, mid and large-scale statistics [4]. The lognormal distribution fits well for the small-scale variations, and in some cases the large-scale variations.

Statistical models will be used for preliminary design and analysis whereas site-specific propagation models will be used for fast and accurate prediction of indoor radio coverage. Simulation techniques such as the image method and brute-force ray tracing methods [11] are commonly used to develop site-specific propagation models. Simulation packages like SIRCIM

[12] that rely on extensive measurement data are also widely used for channel simulations. The ray tracing method is commonly employed to predict the power delay profile of the indoor channel. For geolocation applications, the parameters of importance are the detection of the LOS path and the ratio of signal strengths of LOS path to the sum of strengths of other paths.

Detection of TOA is a function of the multipath structure, receiver specification, SNR and the algorithm used to detect the LOS path. The probability of detecting the LOS path in a Rayleigh fading channel [18] is shown to be dependent on receiver sensitivity and dynamic range. Also results show that the 85% of the profiles observed were either LOS or NLOS [20]. Most of the profiles at short distances have LOS, while at larger distances have NLOS environment. Simulation of the channel provides insight into the architectures that could work best for the purpose.

PROPOSED IMPLEMENTATION

In this project, the object to be tracked confined to a single room or chamber. Multiple receivers are employed to ensure that an LOS path exists between transmitter and some of the receivers. Different algorithms may then be used to obtain the position of the transmitter. One simple algorithm would be to estimate the TOA of the LOS component that can be detected using the proposed scheme. In the NLOS environment, a RAKE receiver is known to work acceptably. A combination of these two architectures will be investigated for its suitability. Alternately, employing many receivers would eliminate the need for a RAKE receiver and keep the design simple and low cost.

Techniques such as Range-difference, Triangulation, Circulation, and Azimuth/Elevation have been used in airborne systems for position location. Triangulation can be used for CW and pulse signals, but is prone to systematic errors. The Azimuth technique can be used for both CW and pulsed signals. It provides better accuracy at high altitudes. The range difference method works well for larger bandwidths, implying shorter pulse width. It utilizes measurements of the TOA of the pulsed signals from three or more spatially separated receivers. Extensive detail of these techniques is provided in [16].

In the proposed scheme, a sliding correlator with a delay-lock loop (DLL) is employed at the receiver for initial synchronization and code lock. A carrier-tracking loop in each receiver provides phase measurements of the received carrier. Different algorithms use the phase information to estimate the position vector. The design will be developed and tested in phases. In the base-band phase of implementation, as shown in Figure 1, only the PN generator at the transmitter and the sliding correlator with delay locked loop are used. The PN code is wired to the sliding correlator for code synchronization and acquisition. An optimal spreading ratio [13] for the system is obtained with this implementation. The PN generator is capable of generating various maximal-length sequences; its implementation is discussed in detail elsewhere [14].

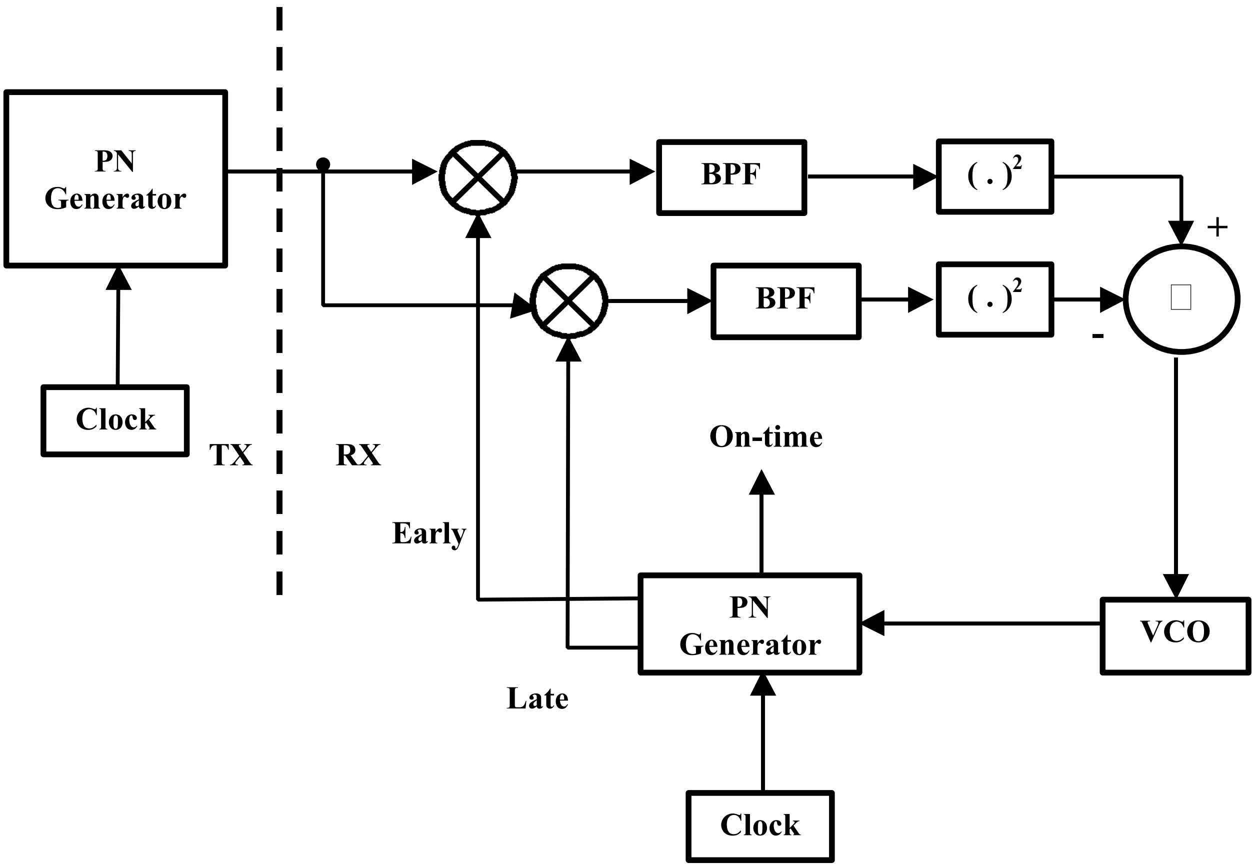

Figure 1. Base-band phase

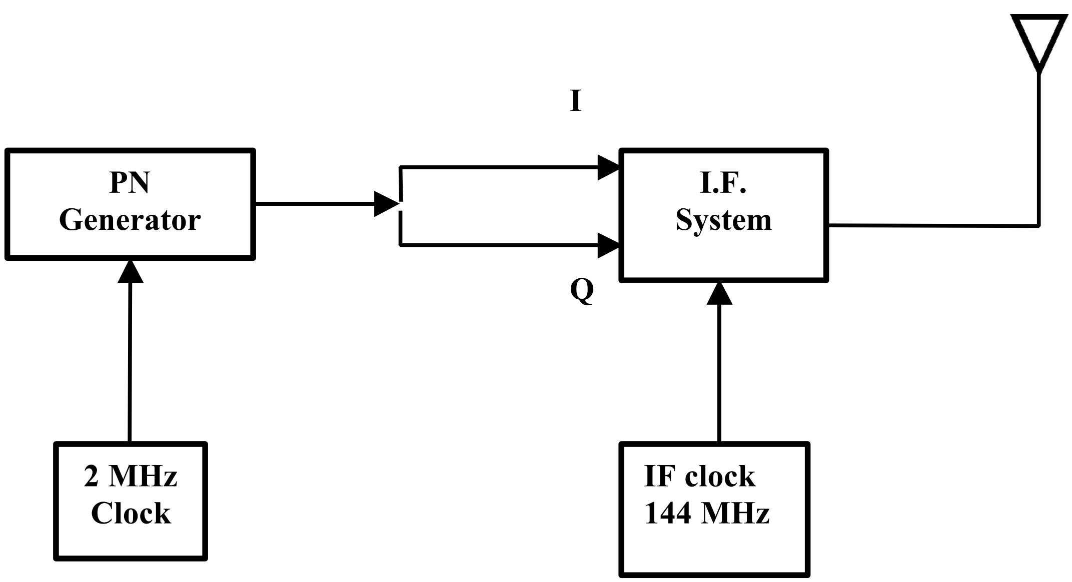

Figure 2. VHF Transmitter Test-bed

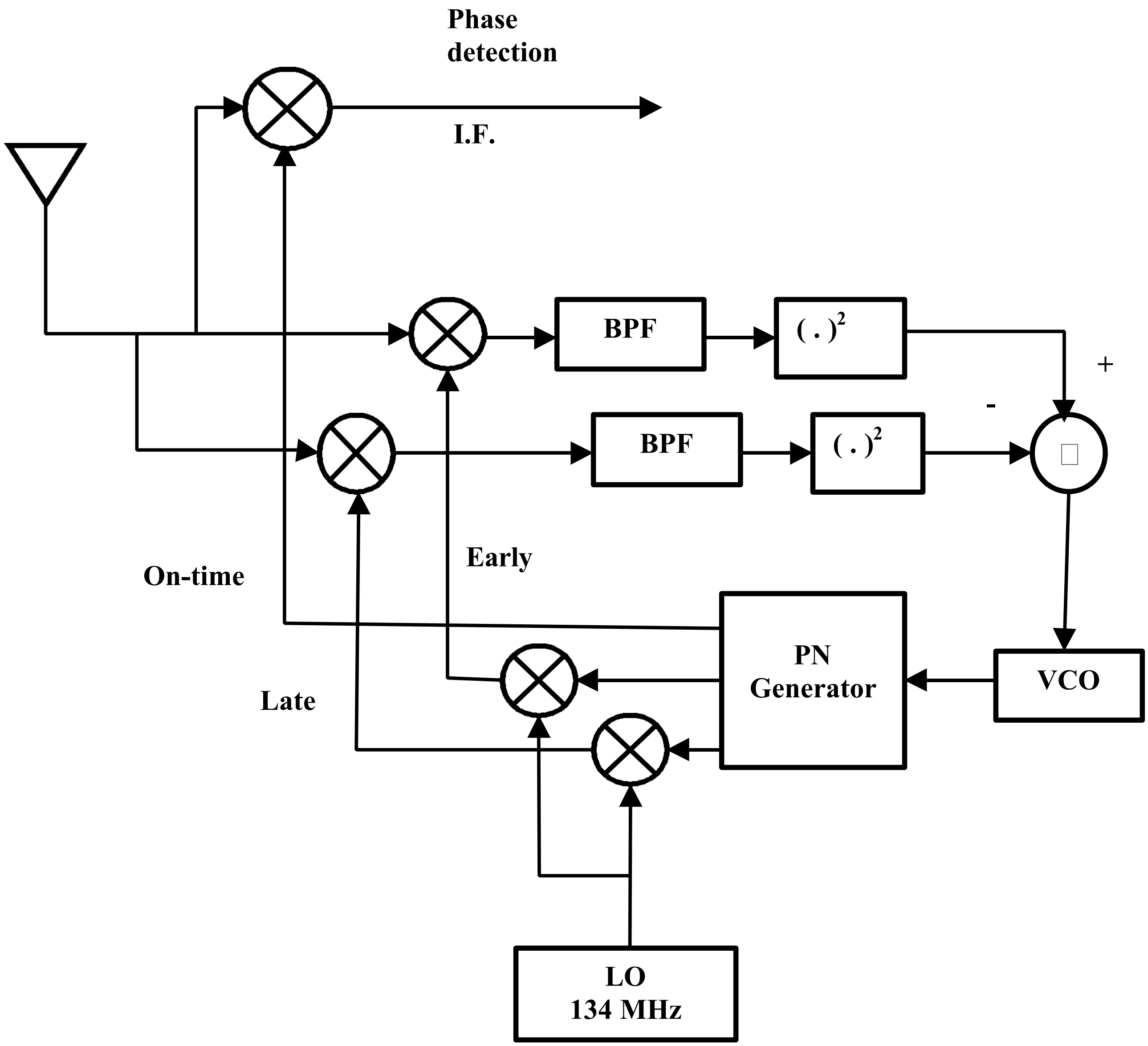

Figure 3. VHF Receiver Test bed

In the VHF implementation phase (Figure 2 & 3), centimeter accurate systems can be made possible by tracking the carrier phase. The system will use the 2-meter amateur radio band, implying a one-centimeter change causes a carrier phase change of 2 degrees. If the tracking loop is made sensitive to phase changes of a single degree, centimeter accuracy is achievable. The PN code is QPSK modulated by 134 MHz Local Oscillator (LO) signal at the transmitting end. The carrier-tracking loop is employed in this stage. A reference oscillator of good short time stability is chosen to detect small changes in phase. This phase allows us to evaluate the performance of the carrier-tracking loop easily. The locally generated PN is clocked at a slightly lower rate of 1.996 MHz and correlated with the received signal. The slip rate is chosen to be 4 KHz. The bandwidth compression factor, K is 500, and resultant bandwidth of the correlation function is 4 KHz. One of the design considerations is phase noise in the receiver that can degrade the performance of the sliding correlator [15]. In the C band design phase (Figure 4), the RF stage is introduced as the front end of the system. A 5 GHz transverter is used as a transmitter. Prior to carrier tracking, the UHF band is translated to the IF frequency. The phase information remains unchanged during this operation. The transmitter under consideration has center frequency of 5.670 GHz and capable of handling a bandwidth a little over 10 MHz, which is sufficient for the purpose. The maximum power output is 200 mW.

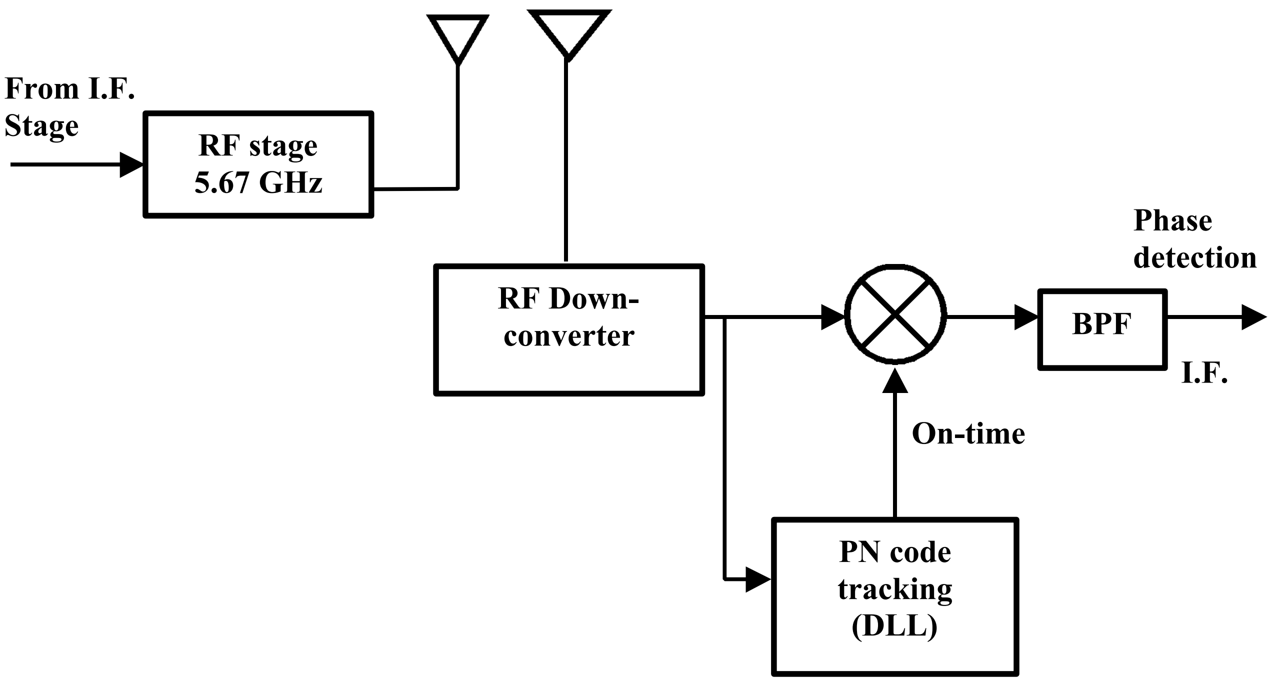

Figure 4. C-band Phase

The final phase of implementation involves all the receivers working in unison and referenced by a common clock (Figure 5). The transmitter is mobile while the receivers are fixed. The time delays introduced due to the cable running between receivers is compensated in calculations. The low cost design can give good performance even with a low accuracy clock. This design is capable of being millimeter accurate even after allowing reduced sensitivity of the phase detector than the earlier stage.

UWB uses small on-off bursts of energy at extremely low power but over an extremely wide section of the radio spectrum. Only a minute amount of energy is radiated at any single frequency. UWB systems fall into two categories: systems that use radar techniques for precise measurements of distance and detection or imaging of objects. The UWB technique is widely implemented as impulse radar. One of the challenges with using UWB systems is obtaining a suitable radiating antenna and electromagnetic interference from other devices that causes an increase in the noise floor [19].

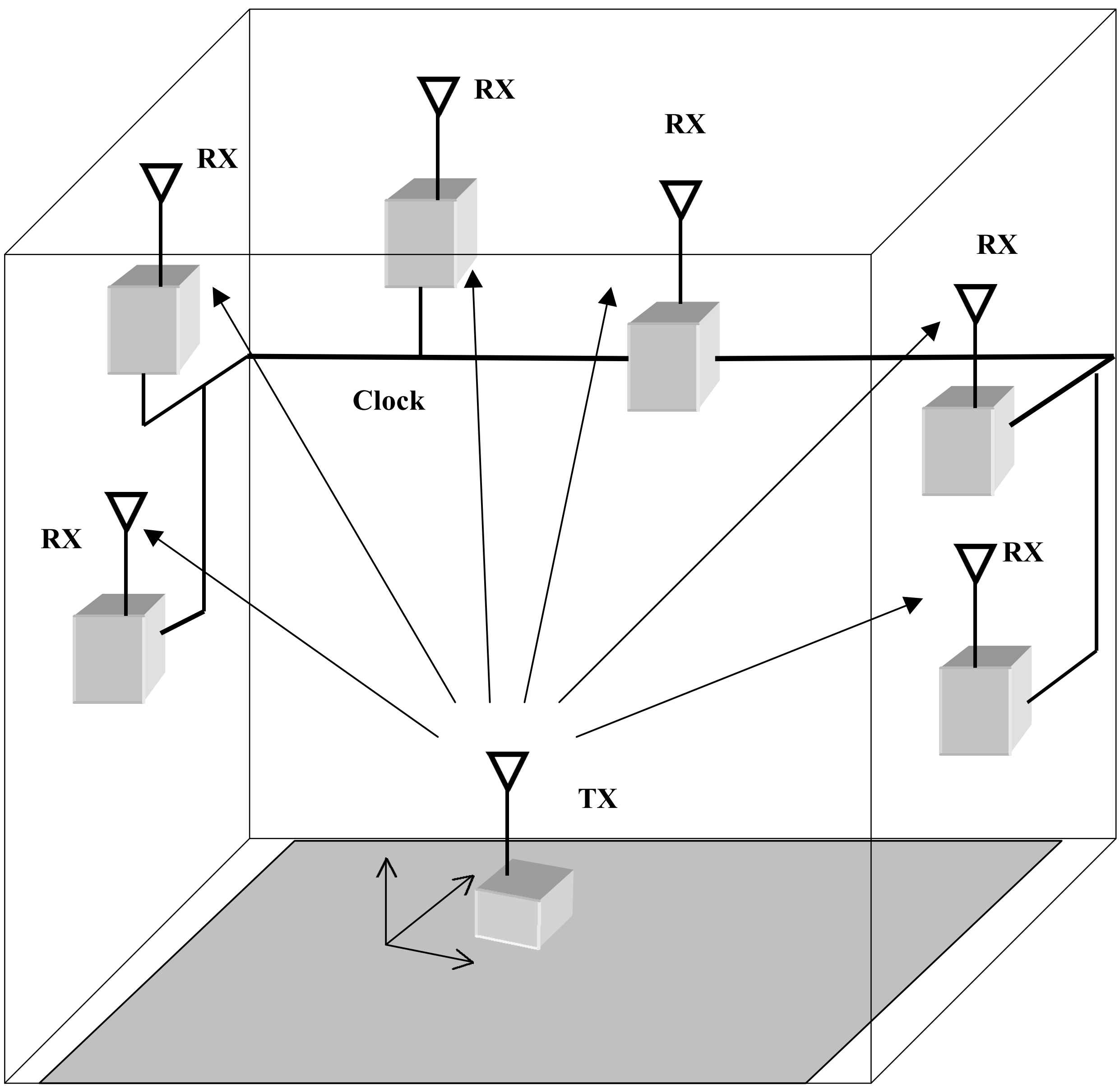

Figure 5. Final Phase

CONCLUSIONS

In this paper, the channel models suitable for position location in the indoor channel have been presented. The channel model will be simulated to see which of the architectures will best solve the problem. Different position location algorithms have been discussed. The performance of these algorithms will be evaluated using computer simulation. A series of test beds has been proposed to verify the simulation results. Using the test beds, we will also investigate the effect of human shadowing, movement of objects, LOS and NLOS measurements on the position accuracy.

REFERENCES

[1] K. Pahlavan and A. Levesque,"Wireless Information Networks", New York: Wiley, 1995

[2] Vickers,R.S. "Ultra-wideband radar-potential and limitations", Microwave Symposium Digest, 1991., IEEE MTT-S International , 1991 Page(s): 371 -374 vol.1

[3] Ichitsubo, S.; Furuno, T.; Kawasaki, R., "A statistical model for microcellular multipath propagation environment", Vehicular Technology Conference, 1997, IEEE 47th, Volume: 1 , 1997, Page(s): 61 -66 vol.1

[4] Hashemi H., "The indoor radio propagation channel", Proceedings of the IEEE, Volume: 81 Issue: 7, July 1993, Page(s): 943 -968

[5] A.A.M Saleh & R.A. Valenzuela, "A statistical model for indoor multipath propagation", IEEE Journ. On Sel. Areas in Comm., Vol. SAC-5, p. 128, 1987.

[6] Hashemi, H., Tholl, D., "Statistical modeling and simulation of the RMS delay spread of indoor radio propagation channels", Vehicular Technology, IEEE Transactions on , Volume: 43 Issue: 1 , Feb. 1994, Page(s): 110 –120

[7] Keenan J.M., Motley A.J., "Radio coverage in buildings", Br. Telecom. Technol. J. January 1990, 8, (1),pp. 19-24

[8] Rappaport, T.S.; Seidel, S.Y.; Takamizawa, K., "Statistical channel impulse response models for factory and open plan building radio communicate system design", Communications, IEEE Transactions on , Volume: 39 Issue: 5 , May 1991,Page(s): 794 –807.

[9] Villanese, F.; Evans, N.E.; Scanlon, W.G., "Pedestrian-induced fading for indoor channels at 2.45, 5.7 and 62 GHz", Vehicular Technology Conference, 2000. IEEE VTS Fall VTC 2000. 52nd Volume: 1 , 2000, Page(s): 43 -48 vol.1

[10] Karlsson, P.; Borjesson, H.; Maseng, T., "A statistical multipath propagation model confirmed by measurements and simulations in indoor environments at 1800 MHz ", Personal, Indoor and Mobile Radio Communications, 1994. Wireless Networks - Catching the Mobile Future., 5th IEEE International Symposium on , Volume: 1 , 1994 ,Page(s): 149 -155 vol.1

[11] Zhong Ji; Bin-Hong Li; Hao-Xing Wang; Hsing-Yi Chen; Sarkar, T.K., "Efficient ray-tracing methods for propagation prediction for indoor wireless communications", IEEE Antennas and Propagation Magazine, Volume: 43 Issue: 2, Apr 2001 Page(s): 41 -49

[12] Krizman, D.M.; Ellison, B.J., Rappaport, T.S., "Modeling and simulation of narrowband phase from the wideband channel impulse response", Vehicular Technology Conference, 1997, IEEE 47th , Volume: 1 , 1997, Page(s): 67 -71 vol.1

[13] Martin G., "Wideband channel sounding dynamic range using a sliding correlator", Vehicular Technology Conference Proceedings, 2000. VTC 2000-Spring Tokyo. 2000 IEEE 51st , Volume: 3 , 2000, Page(s): 2517 -2521 vol.3

[14] Rawlins, G.S.; Belkerdid, M.A., “A fast acquisition technique for direct sequence spread spectrum communication systems”, System Theory, 1991. Proceedings., Twenty-Third Southeastern Symposium on, 1991, Page(s): 2 –6
[15] Kivinen, J.; Vainikainen, P., “Phase noise in a direct sequence based channel sounder”, Personal, Indoor and Mobile Radio Communications, 1997. Waves of the Year 2000. PIMRC '97., The 8th IEEE International Symposium on , Volume: 3 , 1997, Page(s): 1115 -1119 vol.3
[16] Paradowski, L.R., “Microwave emitter position location: present and future”, Microwaves and Radar, 1998. MIKON '98., 12th International Conference on , Volume: 4 , 1998 ,Page(s): 97 -116 vol.4
[17] Pahlavan, K.; Krishnamurthy, P.; Beneat, A., “Wideband radio propagation modeling for indoor geolocation applications”, IEEE Communications Magazine , Volume: 36 Issue: 4 , April 1998, Page(s): 60 -65
[18] Krishnamurthy, P.; Pahlavan, K., “Analysis of the probability of detecting the DLOS path for geolocation applications in indoor areas, Vehicular Technology Conference, 1999 IEEE 49th , Volume: 2 , 1999, Page(s): 1161 -1165 vol.2
[19] Win, M.Z.; Scholtz, R.A.; Barnes, M.A., “Ultra-wide bandwidth signal propagation for indoor wireless communications", Communications, 1997. ICC '97 Montreal, Towards the Knowledge Millennium. 1997 IEEE International Conference on , Volume: 1 , 1997 Page(s): 56 -60 vol.1
[20] Krishnamurthy, P.; Pahlavan, K.; Beneat, J., “Radio propagation modelling for indoor geolocation applications”, Personal, Indoor and Mobile Radio Communications, 1998. The Ninth IEEE International Symposium on , Volume: 1 , 1998, Page(s): 446 -450 vol.1