A Simulation Framework for the Performance Evaluation of Localisation Techniques over WSNs

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***Abstract*— Wireless sensor networks (WSNs) are nowadays considered to be a very active research field. WSNs consist of interconnected small devices, which are managed by users. Their demands in hardware are limited and the usage of particular communication protocols lead in great autonomy. A WSN application is the localization of targets invading in the area covered by sensors' range. This target may be an animal, human, object or anything else. Localization can only take place when the sensors are capable of processing data and of communicating with each other. When these conditions hold, localization is achieved. A simulation environment has been developed in Matlab for studying the above described problem, where the localization algorithm may be integrated together with different scenario parameters. These scenarios have been implemented for evaluating the localization algorithm performance for different mobile object trajectories and speeds as well as for different network topologies. Finally, the evaluation results are discussed and conclusions drawn are presented.**

Keywords-wireless sensor networks, localization, simulation

I. INTRODUCTION

As wireless sensor network (WSN) applications cover a growing number of fields, the need for fast yet accurate exploration of optimal alternatives becomes more demanding, thus necessitating the development of structured and efficient performance evaluation strategies.

An efficient localization algorithm is expected to predict the path of the mobile object with high accuracy. Localization applications using WSNs range from health monitoring to house safety and even to military surveillance [1]. On the other hand, the localisation performance is affected by a series of parameters that need to be addressed and co-evaluated during the simulation process [2]. These parameters are related to the communication channel, to the target mobility pattern and to the localization nodes' positions. The type of signal used for the target position varies from RF to IR and ultrasound depending on their suitability for different application scenarios and on the available power [3]. The mobile target speed and mobility pattern are important parameters as they directly affect the time that the target resides in communication range and indirectly the tracking accuracy. Moreover, the network topology may facilitate or harden the localization task, i.e. a randomly deployed set of nodes has less probability to achieve high communication coverage in the localization area than a pre-defined deployment scheme. Finally, the limited resources of WSNs impose restrictions to their capabilities and performance; the limited memory restricts the use of complicated and demanding algorithms and the limited battery storage restricts the power consumption and extensive execution time [2]. After sensing and processing data, WSN nodes need to consume it or send it immediately to a storage point [4].

Several approaches have been proposed in the literature for the evaluation of localization techniques in WSN deployments. A methodological approach to the evaluation of localization algorithms is thoroughly presented in [5]. Other approaches focus on comparing the localization error with respect to energy [6] and others are limited to customize the simulation environment to specific deployment and application characteristics [7]. However, all of them base their evaluation procedure on theoretical models for the signal propagation, do not consider the particularities of the network topology scheme or the environmental conditions that affect network connectivity and the communication pattern.

In this work, the issue of localisation applicability and performance with WSNs is discussed. For this purpose, a simulation strategy and environment has been developed, incorporating models of all aspects of WSN performance affecting the localisation accuracy. Section 2 presents the most commonly used localisation techniques, whilst Section 3 covers WSN related parameters that need to be considered during a performance evaluation study. Section 4 presents the simulation process and scenarios followed by this work, as well as the simulation environment developed to perform the experiments and Section 5 discusses the experimental results. Finally, conclusions are drawn in Section 6.

II. LOCALISATION TECHNIQUES

As many localization techniques exist in the literature, this work focuses on the most widely used for fixed network topologies and analyses them with respect to the network and mobility parameters to select the most representative one for studying localization performance of a mobile target in fixed WSN topologies.

At the initial phase of the localization algorithm, every fixed node makes known its position to the rest of the nodes in the network. At the end of this phase, nodes keep only their neighbor's positions so as not to overload their memory. Once a mobile target enters the localization area, the fixed nodes attempt to track its path based on their relative distances from the target. The result of the localization algorithm is then either communicated to a node centrally placed in the network area or consumed by the mobile target or even by a set of fixed nodes in the network. This last step depends on the application case.

The complexity of impact factors and varying application cases affecting the localization task success have led to a wide variety of existing localization techniques targeted to specific application requirements. These techniques differ in the type of signal used to estimate the target position, with the most popular being the RF signal, ultrasound, infrared and the received signal strength (RSS). Some techniques have been developed for fixed topologies and others for dynamically changing networks. Focusing on the fixed topology localization techniques, grid and random scenarios are discriminated as the varying impact factors are seriously affecting localization performance.

For grid topologies, the most common technique is the fingerprinting approach, which computes the target position based on the comparison between the RSSI and predefined signal strength measurements stored in a database [8]. For random topologies, the most famous technique is hop-counting, which uses RF signals and hop count tables for every node's neighbors [9].

The work presented in this paper adopts the triangulation technique based on RSSI, which belongs to the hop-counting localization family. This method bespeaks at least three fixed nodes in the vicinity of the mobile target, for the localization to be performed. The mobile target can be tracked inside the triangular area covered by the three fixed nodes in communication range to the mobile, as shown in Fig. 1. The distance among each nearest fixed node and the mobile target is calculated based on the RSSI from the mobile target. This procedure is repeated for all fixed nodes nearest to the mobile target along its path until the mobile target exits the communication area of the WSN.

III. WSN MODELING PARAMETERS

The WSN parameters have been modeled to facilitate the evaluation of the triangulation technique for localization through simulation. These parameters are:

a) the signal propagation model used to translate RSS to distance and vice versa,
b) the fixed nodes topology,
c) the mobile target speed and
d) the mobile target mobility pattern.

A. *Signal propagation model*

Distance computation is achieved based on the RF propagation model developed in [2], which takes into account environmental parameters and the fixed topology impact on the RSSI. As such, the propagation model adopted by this work is based on experimental measurements and is accurate enough and representative of a real-life scenario, as opposed to the theoretical RSS-distance characteristic provided by the TelosB manufacturer [12].

As discussed and concluded in [11], for a RSSI-based triangulation technique to be applied in a fixed topology with satisfactory results, the mobile target is considered to be at 0.5m and the fixed nodes at 0.55m. The RSSI vs. distance characteristic, adopted by [11], shown in Fig. 2, represents a realistic RSSI characteristic, considering the environmental impact on communication and connectivity conditions. The blue characteristic has been quantified to form the RF propagation model during the simulation experiments conducted in this paper.

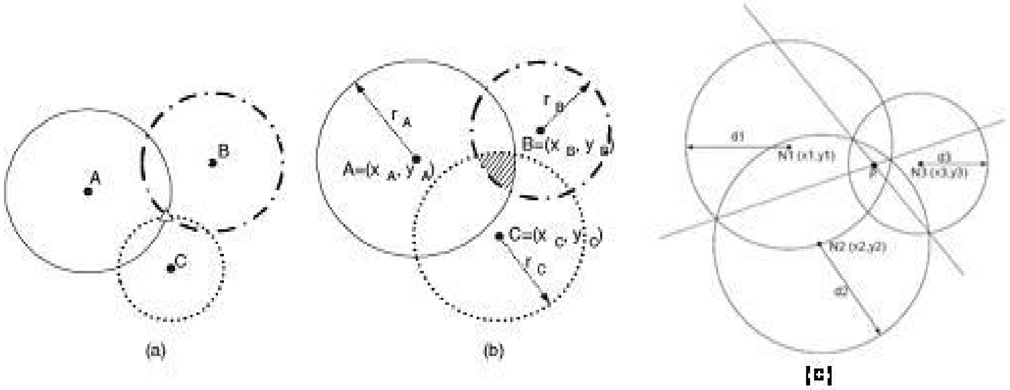

Figure 1. Location calculation based on triangulation

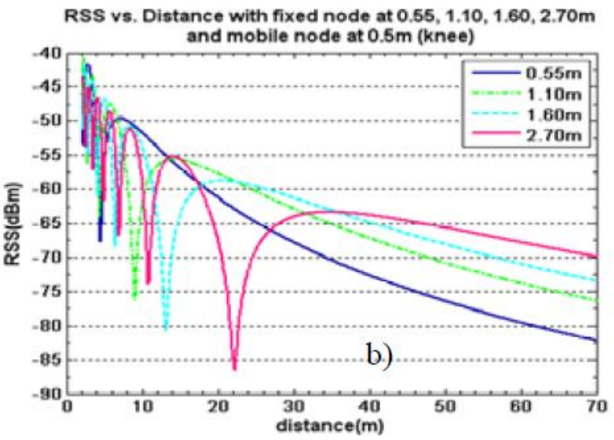

Figure 2. RSSI-distance diagram with mobile object at 0.5m and fixed nodes at many heights

B. *Network Topology*

The network topology has a high impact on the localization accuracy, as the fixed nodes positioning defines the communication links quality with the mobile target and thus the localization success. If the fixed nodes are deployed in a grid, the probability that the mobile target is reachable by at least three fixed nodes is high and thus it can easily located. On the other hand if the network topology is random, the communication quality is less probable to be good in the whole localization area, leading to low mobile target connectivity to the fixed nodes and thus degrading localization performance. Following the analysis of [10], the network topology of the fixed nodes is considered to be a grid with distance of 55m among them in order to achieve high communication quality and thus good connectivity.

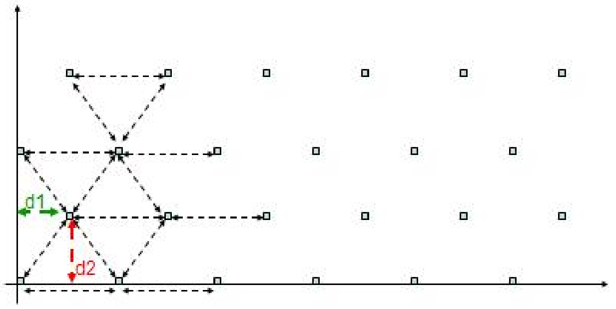

Figure 3. the Grid topology scheme used in the experimental analysis

C. *Mobile object parameters*

The two parameters affecting localization accuracy are the speed and the trajectory of the mobile target. If the speed of the mobile target is low, the three nearest nodes have enough time to apply localization calculations and to predict its position. For low mobile target speed, the three fixed neighboring nodes may need more rounds of predictions for increasing the localization accuracy. On the other hand, if the mobile object moves too fast, the time window during which the mobile target moves in the fixed nodes' communication area may not be long enough to allow message exchange and position calculation.

As far as the second parameter is concerned, namely the mobile target trajectory, its impact is lower relatively to speed. However, in combination with the fixed nodes topology, it can make communication very difficult and thus the localization task too hard. In this work, the impact of both the mobile target's speed and trajectory on localization accuracy are studied.

IV. SIMULATION PROCESS AND SCENARIOS

The evaluation methodology followed in this work assumes a fixed network topology and a mobile target moving in the network range. The localization technique adopted in this work is triangulation and the parameters affecting its performance are modeled in a simplified yet efficient way in order to provide a complete set of impact factors for inclusion in the developed simulation framework.

As shown in Fig. 4, the simulation-based evaluation procedure starts when the mobile object starts moving from a known starting point in the WSN covered area. While the mobile object enters the localization area, the fixed nodes start communication with it in order to compute the mobile object's RSSI. The three fixed nodes with the highest mobile object's RSSI are considered to be the nearest to it and start the localization process. The three fixed nodes translate the RSSI into distance based on the radio propagation model developed in [2], which depicts the real signal propagation of the TelosB platform [12]. Based on the range of each fixed node the algorithm calculates the points at which, the three communication ranges intersect. Thus, the triangle that the localization algorithm needs has been formed and its middle point is computed. For simplicity reasons, the mobile target position is assumed to be the center of the triangle formed by the communication range of three nearest fixed nodes. This procedure is repeated by the fixed nodes corresponding to the nearest range of the mobile object trajectory until the mobile object leaves the network area.

The impact factors on the localization algorithm performance form the set of simulation parameters and their combination the relative simulation scenarios:

- fixed network topology: grid and random
- the speed of the mobile object: 5Km/h (man walking) and 15Km/h (man running)
- the trajectory followed by the mobile object: beeline and random

The performance metric of the localization algorithm is the localization error.

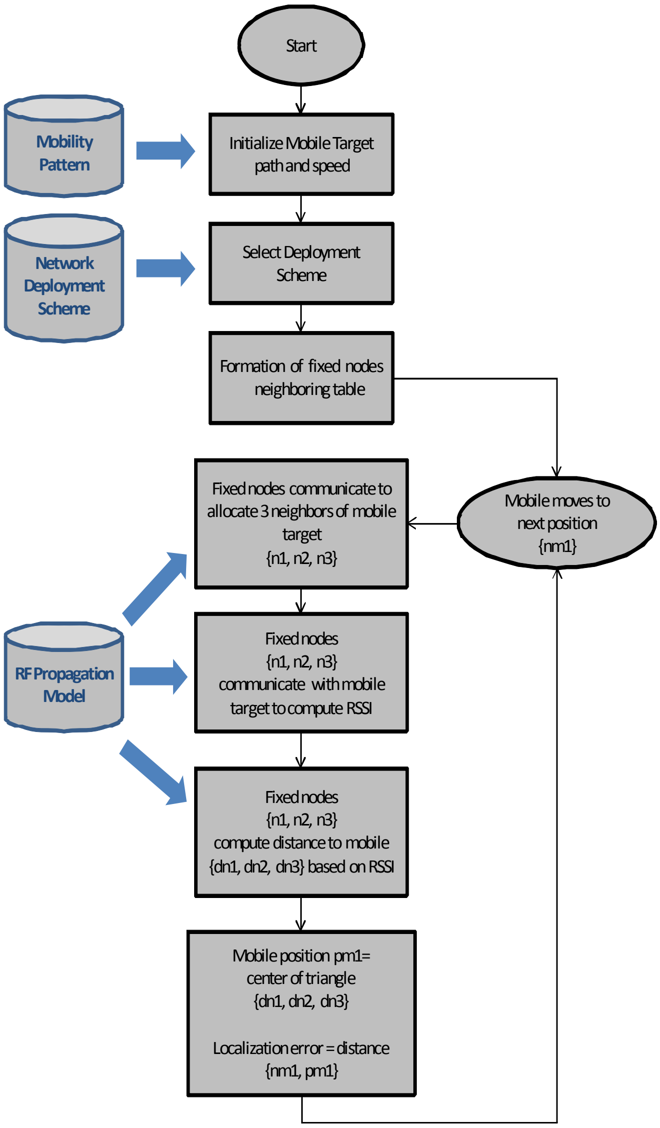

Figure 4. Evaluation Process Diagram

V. LOCALISATION SIMULATION RESULTS

The simulation environment developed has been implemented in MATLAB 2009. The results of the simulation scenarios are presented and discussed in the following. Each figure depicts a ground plan (x-y axes grid in meters) of the network, with fixed nodes represented by blue squares, the blue line representing the actual trajectory of the mobile target, the small red crosses representing the positions predicted by the triangulation algorithm and the light green area representing the communication range of the mobile target to the nearest fixed nodes.

Fig. 5 and Fig. 6 show localization results of a mobile target in a grid fixed topology moving slowly (speed = 5Km/h), in a beeline and a random path respectively. The average localization error is 3.7m and 5.6m respectively, with low variance. As long as the mobile targets moves at low speed within the communication area of fixed nodes, the effect of its trajectory on the localization success is relatively low.

On the other hand, when the speed of the mobile target is tripled for the same network conditions and fixed nodes processing time, the percentage of successfully received packets is reduced by 30%, thus leading to position miscalculations. As shown in Fig. 7 and Fig. 8, the number of position calculations is considerably reduced to 53% for the straight path line and to 71.5% for the random path. Another conclusion drawn from the 4 latter figures is that the localization algorithm is easier to predict the straight path than the random path with the localization error to be 4.5m and 5.8m respectively. The red spots that the algorithm predicts in straight move is nearest than them in random move. Therefore the prediction in straight move is better than the random move.

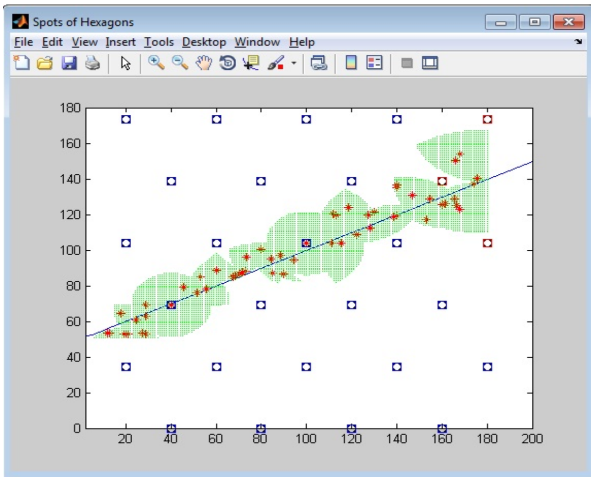

Figure 5. Straight move in grid topology with speed 5km/h

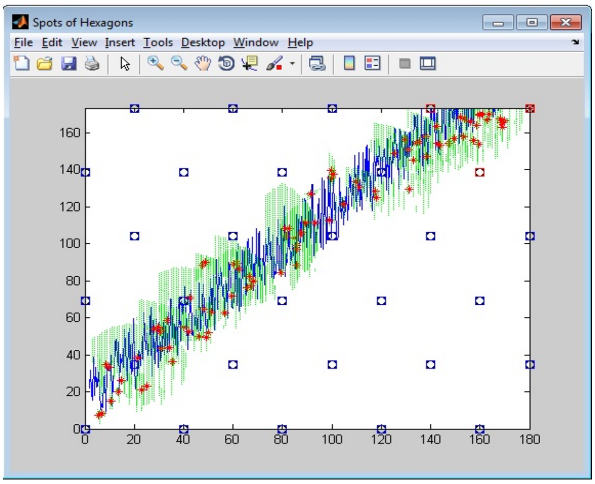

Figure 6. Random move in grid topology with speed 5km/h

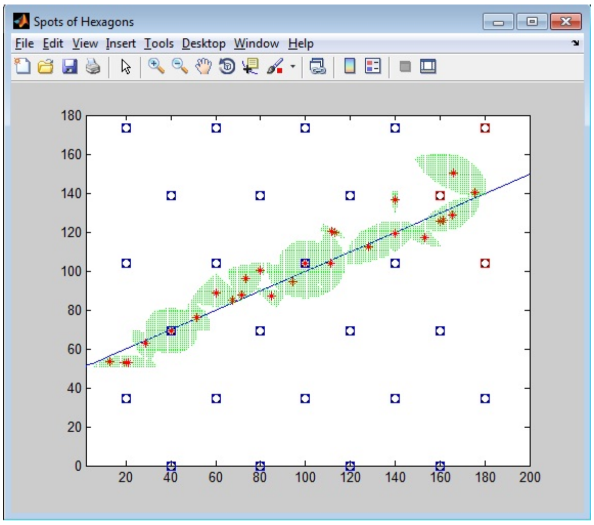

Figure 7. Straight move in grid topology with speed 15km/h

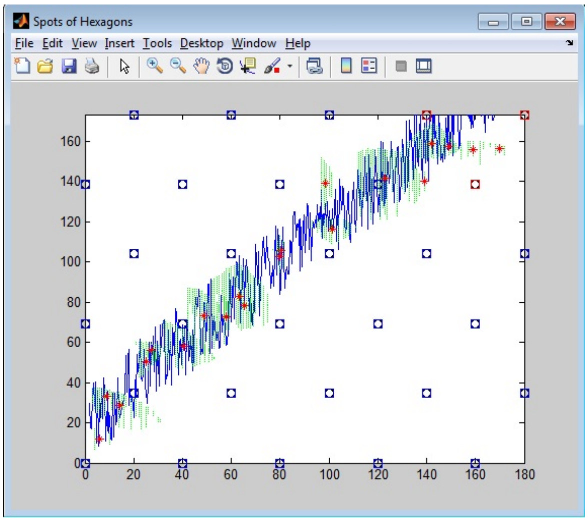

Figure 8. Random move in grid topology with speed 15km/h

Fig. 9 and Fig. 10 depict the mobile target localization in a random fixed grid, moving at slow speed of 5Km/h. It is evident that the random placement of fixed nodes narrows the communication range along the mobile target trajectory, thus leading to localization failure in spots, where 3 fixed nodes cannot be found within range of the mobile target. That is the reason why, in Fig. 9, the mobile target trajectory from points (140,110) until (200, 150) is not tracked at all.

This is not the case for the random mobile path shown in Fig. 10, where the mobile target has more spots within the communication range of fixed nodes, causing the prediction to rise up to 20.5% more than the straight move. However, it must be noted that for the random deployment scheme, even though the prediction level increases, the localization error is higher. It is, therefore, evident that the fixed nodes should be deployed in such a way as to cover as evenly as possible the localization area from a communication point of view.

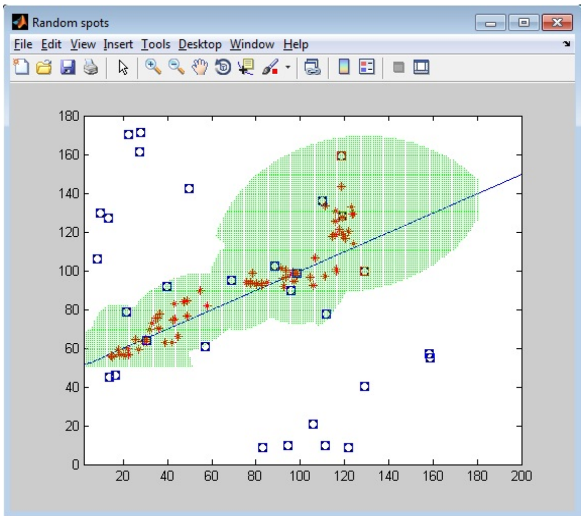

Figure 9. Straight move in random topology with speed 5km/h

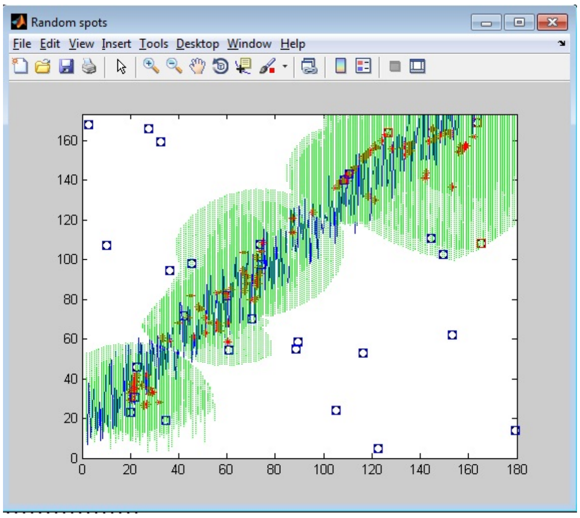

Figure 10. Random move in random topology with speed 5km/h

Fig. 11 and Fig. 12 show localization results of the worst-case scenario, where the network topology is random, the mobile target moves at high speed of 15Km/h and its path goes out of the fixed nodes' communication range for a high percentage. The triangulation algorithm performance is seriously degraded with a low percentage of localization success close to 10.6m and 38.3m for beeline and random trajectory respectively.

Overall, for the triangulation technique to achieve high accuracy, the network topology should be carefully studied to be at least similar to a grid. The mobile target trajectory plays a minor role for the localization error, as long as the target stays within the fixed nodes communication range. Finally, the mobile target speed has high impact on localization performance but as this is a parameter that cannot always be managed, the density and deployment scheme of the fixed nodes is again a parameter that should be used to compensate to achieve the localization goal.

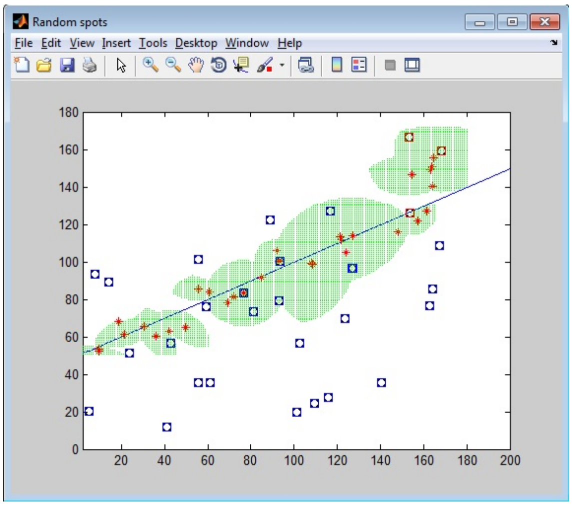

Figure 11. Straight move in random topology with speed 15km/h

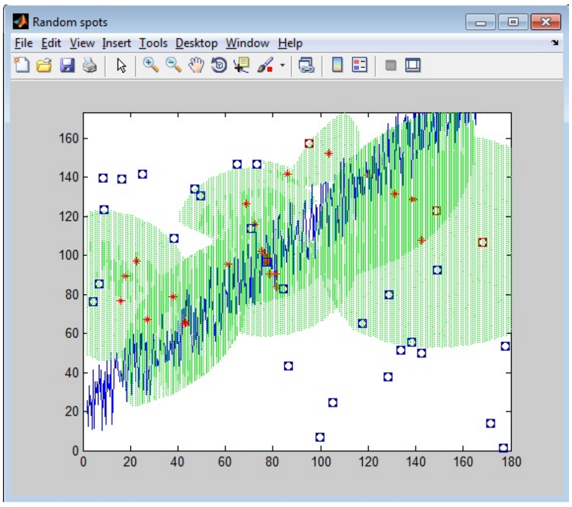

Figure 12. Random move in random topology with speed 15km/h

VI. CONCLUSIONS

This papers deals with the issue of localisation applicability and performance in WSNs. For the evaluation of localization techniques, several approaches have been studied and the triangulation technique has been chosen for the case study. WSN characteristics have been modelled and a simulation strategy has been developed. The simulation environment, developed in Matlab, incorporates these models of all aspects of WSN performance affecting localisation accuracy. The presented methodology principles may be applied to other localization evaluation attempts and be cross-validated by experimental setups.

The simulation environment that has been developed follows a holistic approach covering all aspects of WSN nature and as such may be generalised to incorporate a library of localization techniques. Moreover, further enhancements of the type of evaluation scenarios may support the applicability study of existing or new localization techniques to different applications i.e. the variation of network topology schemes or the number of mobile targets. Overall, the simulation framework has been developed in a modular way as to cover the mobility parameters in combination to the network topology and radio propagation characteristics and is extensible as to be able to incorporate more evaluation and impact parameters in the form of libraries.

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