Localisation strategies in ultra-dense networks

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***Abstract*—The current trend of growing connectivity results in Ultra Dense Networks (UDN) that increases the load of the network as well as generates new opportunities. This report presents an overview of strategies to improve localisation within 5G technology in UDNs. These strategies will be connectivity oriented and by measuring the time of the transmissions or the direction of the signal, a position can be estimated. As more nodes are used in a UDN, a cooperative strategy could be implemented. The location information could be utilized to improve the communication with features such as predicting movement and demands, estimating the channel and effective scheduling. The report include no experimental data or new information, but aims to generate an overview of localisation methods that can be implemented with the new 5G network.**

I. Introduction

The demand for high performance wireless communication has increased during the past decades all over the world. The connectivity in the world is continually increasing and is going toward connectivity in cars and other appliances and is called the Internet Of Things(IoT). Simultaneously there is an increase of communication from device to device (D2D). As more and more devices are connected these create denser networks with more connections within a smaller area and especially in areas with large populations. Along with the development of a larger number of connected users there comes increasing amount of information that could be utilized to improve the communication. The location information of the users are an important aspect of this. The problem however is that all devices are not equipped with GPS sensors since it is both a cost in hardware, power consumption and precision, which increases the need for other localisation strategies. If more devices is becoming connected the information of these devices can also serve basically as sensors and creates a large wireless sensor network (WSN).

The aim of this report is to present the strategies and challenges for how localisation is be conducted in ultra dense networks. The report will also discuss the possibilities of an reliable localisation method, how this information could be used to improve communication according to future demands.

This report will not present any new data or results. Although it present up-to-date strategies and technologies, it will not include technological details, including mathematical derivation or simulation but rather implementations on a conceptual level.

This report will start to present general background information about the major concepts discussed in the report. Then present strategies an analysis of these. This report is concluded with a presentation of how the location information could be utilized in future technology.

II. Background

This section will present some background information about some important areas for localisation. The purpose of this is to provide a general sense of the importance of localisation and a context of this report.

A. Wireless Sensor Network

A WSN is a network of sensor nodes used to monitor a certain object or factor. It could be everything from the weather and environment, military surveillance or healthcare [1], [2]. In WSN the information is useless unless the location of the sensor is known [3]. Since there often are a large number of nodes in the network there is a cost, both financial and in terms of energy, to equip each node with a GPS-tracker, [4]. Techniques for localisation often involve nodes to relate the position to the other nodes and as a combination the position is derived. To optimize this is to have as reliable a localisation as possible, [4]. Improvement in localisation strategy will yield not only more reliable information but also an increase in the capacity of the network.

B. Ultra-Dense Network

UDN is a new phenomenon describing the communication network as the amount of devices connected to each other increases. In UDNs access entities are densely distributed in the coverage areas of base stations. The density of the access entities may exceed the density of users [5], which leads to high data rate transmission in the networks. UDNs may also introduce issues which are different from previous wireless networks in several aspects, including interference, mobility and resource management [6]. Main factors addressed by UDNs, such as node randomness, affect the accurate localisation estimates [7]. Meanwhile, these randomness nodes usually have low cost and power in UDNs [8]. It introduce limitations for localisation strategies, such as ToA and RSS, to obtain high precision measurements. Localisation apporaches and methods introduced in UDNs have to consider the new factors and address for localisation in 5G UDNs.

C. Automotive V2V

One aspect that is important with the current development of 5G is the ability of having a less time consuming and more reliable communication with a larger number of nodes. When the location is known this information could be used to improve the performance of the communication. This information can be used for example to improve the estimation of the wireless channel and decrease the time when communicating which leads to a larger data rate, [9] [10]. This could be applicable in for example communication in vehicles where a fast and reliable localisation and communication is crucial, [10]. Another application is to use the location information to improve the routing in a cluster of nodes to save time and to reduce the complexity, [11], [12].

III. Localisation

Determining position by only using the global positioning system (GPS) may not always be sufficient [1]. The lack of coverage and penetration through blocking environment makes its reliability insufficient in urban settings. In this section strategies originally used in ultra-wideband (UWB) communication will be presented. In these communication systems the estimation of users locations can be obtained in different ways. The users location relative to one or multiple access points or anchors with known positions and can be used to calculate the users position, this is illustrated in figure 1 where only the distances relative to the access points are needed to get a position if the access points has known positions.

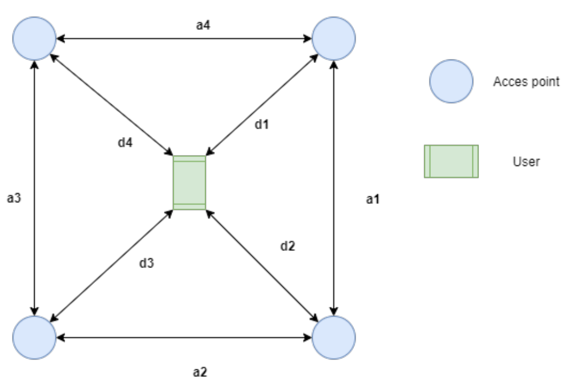

Fig. 1. The figure illustrates how localisation of a user relative to the access points can be obtained by knowing the distances d1 to 4 if the distances between the access points is known a1 to 4.

Since the strategies presented in this section is based on UWB communication it will assume that a line of sight (LOS) connection to work properly and errors might occur when the only non-lign of sight (NLOS) communication is conducted [13]. However, with UDN the cell sizes are reduced and this results in more LOS connections.

A. Distance measurements

This section describes the most common methods of estimating distance between users and access points. The methods

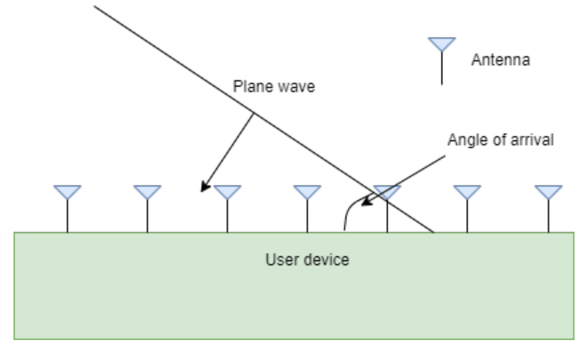

Fig. 2. The figure illustrates the concept of obtaining the angle of arrival from an incoming signal when multiple antennas are used.

presented below are all used depending on the specific implementation.

One method of determining the distance to an access point is the received signal strength (RSS), that estimates the distance between the user and the access point by sending a pilot with a known power and then calculates the distance through the path loss [14]. Another way is to calculate the time of arrival (ToA) which is a method that estimates the distance by using the propagation time of the transmission. However, this is a method that is built on a pilot signal sent only in one direction and leads to that it is sensitive to synchronization error between the clocks of the devices and is therefore hard to implement and not viable enough [14]. There are other methods to obtain the distance, called round trip time of arrival (RToA) and time difference of arrival (TDoA) where the synchronization is not as vital. The RToA is not as synchronisation sensitive because the distance is calculated from both up and down link and when the packet is back at the user it contains the wait time at the node as well as the time that the transmission took up and down link [1]. The TDoA is executed by calculating the time difference between access points and the user when a up-link pilot is sent and that way locate the user. This however requires a location measurement unit that calculates the clock differences between the access points before that position is sent back to the user [13].

B. Direction of arrival

Another approach is to use the direction that the information is sent and this is called direction of arrival (DoA) [13]. This requires that the user has some kind of smart antenna that, with help of multiple antennas spaced with a known distance apart, can calculate the direction that the signal arrived from. The direction is determined from the incoming angel of the signal and the time difference of the arrival signal. This is illustrated in figure 2. However, this leads to an increased hardware cost.

C. Cooperative Localisation

As more complex networks are being used, such as the expansion of IoT and WSN, the need for an efficient localisation strategy is growing. A method of localize the growing number of nodes in a efficient way is Cooperative localisation. This is a way of determining the position of a node relative to the neighbour or an anchor node with a known position [1]. The strategy is illustrated in figure 3 where the two users can not get their position by only measuring their distances to the access points, but with the D2D communication they can together determine their respective position.

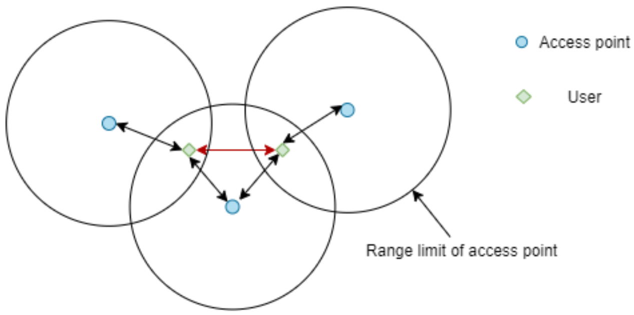

Fig. 3. Illustration of how cooperative localisation work, here has the users only 2 connections to access points with known position. With help of D2D communication, marked in red, get their positioning relative to each other to complement for the lack of direct access to access points.

IV. Analysis of localisation methods in Ultra-Dense Networks

This section will analyse how localisation is performed between users and access points. The basic concept builds on the localisation techniques presented in section III and this section will describe how it is implemented.

A. Location tracking and prediction

The localisation methods in the previous section create an estimated position of the user by using different access points or, alternatively, using one access point and different methods. This is the basics of how the tracking is performed and with this information it is possible to predict where a user will be the next time data will be sent. It is done by using a Extended Kalman filter (EKF) to predict the trajectory. The Kalman filter is a recursive filter that includes two steps, prediction based on prior knowledge and then an update step based on current measurement. The EKF is an variant of a Kalman filter that can handle a non linear model. By not doing the update step in the EKF but only the prediction step a trajectory is predicted for several time instances ahead [14]. This step is not based on new measurements but information received for previous time instances.

B. V2V Localisation

As the car industry moves forward in autonomous driving the need for quick reliable data for mapping of the surroundings and the need for V2V communication increases. This is all things that the 5G network will be able to support in time but for the automated driving to work the localisation is critical. With the new 5G network the properties with D2D communication with large bandwidths and ultra dense network theses can together create a system with ultra-accurate positioning and mapping of vehicles and surrounding users and environment [15].

C. Potential improvement for localisation strategies in UDNs

The potential research on localisation strategies in UDNs is to achieve best positioning accuracy. ToA-based methods started with time of arrival for localisation. Several relative methods are derived such as RToA and TDoA, which have potential in the future to improve the positioning accuracy.

Another aspect is Cooperative/Connectivity-Based localisation, one of the examples is Cramer-Rao lower bound (CRLB). Compared with ToA-based methods, Connectivity-Based localisation only utilizes connectivity information to locate nodes [16]. In certain scenarios nodes in UDNs have no ability to achieve measurements based on ToA, TDoA or RSS [16]. In that case, because of the hardware limitation, connectivity-based localisation methods are often prefered in UDNs.

V. Location aided communication

Knowing the location of the users in the network has a lot of potential to improve performance on the communication. This section will discuss a few potential advantages and implementation of location aided communication.

A. Channel estimation

A possible way to improve wireless communication is to utilize the locations of the users, in order to get an better estimation of the channel. By using the package with the location information to estimate the channel the process time is greatly reduced, [10]. This is a time saving method that minimizes the number of transmissions while still getting an accurate estimation. Since wireless communication is greatly affected by the environment it is vital to get an accurate estimation of the channel properties in order to guarantee a reliable communication.

By building a channel database with information about the static environment, such as an buildings in urban environment, the prediction will be more accurate since the major statistical properties are mapped, [17]. This database could help predict for instance the expected shadowing when a user is moving in a urban environment in a more accurate way then with less prior knowledge of the channel.

These methods are very useful in autonomous systems that require real time awareness such as self driving cars. The systems speed, accuracy and robustness of communication are in focus and these aspects could be improved by location aided communication.

B. Predicting demand

By using the location of their users and the possibility of predicting the movement some advantages can be gained and result in a more adaptive and dynamic network. The demand can be anticipated by knowing the location, prediction and need of each user. The entrance of a user with a larger demand in a cell would normally result in a poor quality of service to the current users but by predicting this event the network could adapt before and reduce the affect of the new user, [14].

C. Channel prediction and scheduling

In a UDN the channel estimation can be more precise when localisation strategies are applied. For example in traffic if a truck drives by, the user will experience shadowing. However, if prediction strategies are used, like the one described in section IV-A, temporary loss in the channel can be estimated and the system get the possibility to reschedule because of this and can buffer up before the temporary disrupted channel. This is basically giving a water-filling approach more information to work with to reach optimal performance [18].

VI. Discussion

The combination of the growing UDNs with its smaller and denser cells, together with cooperative localisation, strategies previously used in UWB communication probably can be used to improve the localisation in the network. This because of the increased probability that enough LOS channels can obtained as the network gets denser. When looking at the usages of localisation there are basically three different areas that can benefit from increased precision in positioning. There are aided communication, actual positioning and mapping of the surroundings. One of the industries that is in need of all of these is the car industry, in particular self-driving cars where the position of a moving vehicle is important, to know how it should interact with its surrounding. For the vehicle to be able to react to its surrounding, it has to be mapped with sufficient precision with high speed and reliability. The robustness and reliable of the information is theoretically obtained in UDNs since then a cluster of devices can act as a WSN to map the surrounding so the car can get sufficient data. However, for these large network to work, the communication has to be very efficient to be able handle the high capacity. Here comes the location aided communication in to play, it is increased by more efficiently estimating the channel with the methods discussed in section V and is a way to create a more efficient communication network which is required for the self-driven cars to be safe.

A. Challenges

As the possibilities of the expanding network increases so does the complexity of the algorithms controlling the information flow over it.

Another aspect that needs attention is the reliability of these localisation methods and to what extend this information can be used for example for assisted driving or in the future self driven cars. These kinds of systems requires precision in the location information.

The localisation methods mentioned in this report are considered accurate in UDNs. However in absence of dense networks they might become inadequate which is important to solve for the self driving cars to work completely.

Extended localisation uses of devices also opens a ethic dilemma how much the user accepts the localisation without feeling that it risking violating the user rights and how these obtained localisation information can be used for surveillance.

VII. Conclusion

The increase in communication between devices results in denser networks. In 5G communication the networks will be increasingly denser and ultra dense networks appear with more connections within a small area with a high population. The improved speed and bandwidth of the 5G network will results in new possibilities of how devices interact with each other. The advantage of the UDN is that it will support a more connected and automated living, but it will also increase the complexity of the network. Localisation seem therefore be a important pillar to support the UDNs communication capacity as well as the improved possibilities within autonomous systems and IoT. The localisation seem to be more reliable in the UDNs but as the connectivity in areas decreases, usages of multiple localisation strategies can enhance the localisation accurate as usages of strategies with distance measuring like RToA combined with DoA increases the robustness of the localisation. However, these strategies still requires that there is enough of connected devices so if a car is running on a highway without trafic away from a UDN, these UWB based strategies will stop to work.

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