SPECIFICITIES AND IMPROVEMENTS OF APPLYING COOPERATIVE LOCALIZATION IN 5G

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ABSTRACT

In this article, we want to emphasize the techniques and characteristics of cooperative localization applied to 5G. The concept of cooperative localization was first proposed by U.S. Air Force researchers in the early 2000s. It was developed as a way to improve the accuracy of positioning systems by using multiple sensors to estimate a position. The technique has since been applied to a variety of applications, including robotics, navigation, and autonomous vehicles. This type of localization based on device-to-device communication is garnering more and more interest with the arrival of the 5G network. The 5th generation has many features that allow for enhanced localization results. So, the main objective is to enhance the accuracy of position estimation. Cooperative localization is an emerging technology that relies on the use of multiple nodes to localize a target in a three-dimensional space. Cooperative localization leverages the use of distributed nodes to collect data from the target and then triangulate the target's position. The nodes then transmit the data to a central server, which can then calculate the target's exact location. Cooperative localization is becoming increasingly important in 5G networks due to its ability to improve network reliability and accuracy. There are many techniques and methods that can be used, including MultiDimensional Scaling and CrossOver – Multiple Way Ranging which we are particularly interested in. Unlike traditional localization techniques such as simple device to device communication or global positioning system that use at most two or three reference nodes, cooperative localization can be based on even more nodes of different types.

Keywords : Cooperative Localization, D2D, CO-MWR, Clustered MDS, 5G

INTRODUCTION

Currently, the applications of localization in our daily lives are becoming increasingly numerous. This implies an increase in the number of Location-Based Services (LBS). There are several localization systems, such as satellite tracking systems and systems using terrestrial sensors, each of which has its own advantages and disadvantages. We will pay particular attention to localization using the mobile network. Unfortunately, this type of localization is less efficient than the others in terms of criteria like precision and availability. This is why mobile network localization techniques are not used for major applications such as Google Maps.

Research has been done to find a solution that could solve or reduce these problems in the 5th generation of mobile network. One of the most promising solutions is cooperative localization which allows device to device or direct interaction between mobile terminals to estimate their position. However, it requires the implementation of a specific type of algorithm called a cooperative algorithm.

Cooperative localization is a key technology for enabling 5G networks. Cooperative localization allows for increased accuracy and robustness of positioning in 5G networks, by combining the positioning capabilities of multiple nodes. This is especially important as 5G networks are expected to be more densely populated than previous generations of networks, which increases the likelihood of obstructions and interference. With cooperative localization, each node in the network can use the position of other nodes to more accurately determine its own position, enabling more precise and reliable positioning in 5G networks. This is especially important for applications such as autonomous vehicles, which rely on accurate positioning for safety and efficiency.

In addition, we are going to show that having a distributed network (through the Clustered MultiDimensional Scaling) of 5G base stations across different locations can also help to provide a more accurate location estimate.

Firstly, we are going to start off with state of the art and important basics around the field of object localization and localization techniques.

Secondly, we'll look at some algorithms that can be used in the context of cooperative localization like Two Way Ranging, CrossOver – Multiple Way Ranging, Classical MultiDimensional Scaling or Clustered MultiDimensional Scaling, and we are going to discuss their respective roles and performances in the localization steps.

Finally, by running simulations through an application developed, we will observe the characteristics and results of the localization algorithms.

Table 1. List of abbreviations

Abbreviation	**Definition**
AOA	Angle Of Arrival
BS	Base station
CF	CrossOver Frame
CO-MWR	CrossOver Multiple Way Ranging
CRLB	Cramer-Rao Lower Bound
CSI	Channel State Information
D2D	Device-to-device
GDOP	Geometric Dilution Of Precision
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IoT	Internet of Things
LBS	Location Based Services
LoT	Location of Things
MDS	MultiDimensional Scaling
MIMO	Multiple input multiple output
MT	Mobile Terminal
PVT	Position, velocity, and time
RMSE	Root Mean Squared Error
TDOA	Time Difference Of Arrival
TOA	Time Of Arrival,
TWR	Two Ray Ranging
WINNER	Wireless World Initiative New Radio

STATE OF THE ART

Cooperative localization

Compared to classical localization, cooperative localization provides solutions to many points such as the lack of reference stations or the localization accuracy.

i. Location of Things (LoT)

With the growing need for precise location, a sub-domain of the Internet of Things (IoT) called LoT (Location of Things) is entirely devoted to the estimation of the positions of these nodes. In this field, cooperative localization algorithms or cooperative algorithms play an essential role and make it possible to open up to revolutionary applications.

ii. Classical cooperative algorithm

Cooperative algorithms or cooperative localization algorithms also make it possible to determine the distance between a transmitter and a receiver. They are generally used in wireless sensor networks. TWR is the classic algorithm used in most cases.

Two way ranging is the classical method of distance measurement in which the difference in the time of flight of a signal is measured between two points. It is commonly used in navigation systems such as GPS. Crossover multiple way ranging is a method of distance measurement in which the difference in the time of flight of a signal is measured between multiple points.
We'll focus on CO-MWR (CrossOver Multiple Way Ranging). While it's not typically used in network-based localization, it can be used in some cases. For example, it can be used to determine the relative positions of nodes within a wireless network, or to localize a mobile device within a network. It can also be used to track the changes in a network's topology. Additionally, CrossOver Multiple Way Ranging can be used to determine the position of a device in an indoor environment, such as a shopping mall or office building.

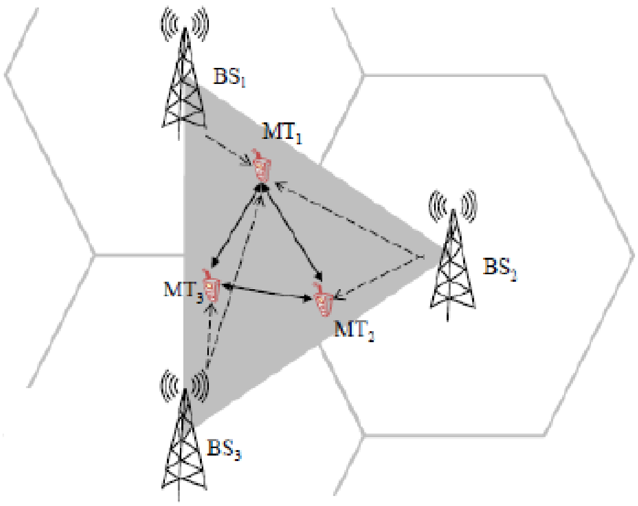

Fig. 1. Illustration of cooperative localization

Distances measurements in cooperative localization

In conventional methods, distances measurements are based on time estimation (TOA: Time Of Arrival, TDOA: Time Difference Of Arrival, …) or angle estimation (AOA: Angle Of Arrival, …).

In cooperative localization, we use a cooperative algorithm to compute the distance between transmitter and receiver.

i. TWR

TWR or Two Way Ranging is a technique used for distance estimation in a cooperative location. The TWR algorithm is suitable for D2D communications according to the specifications of the IEEE 802.15.4a [6].

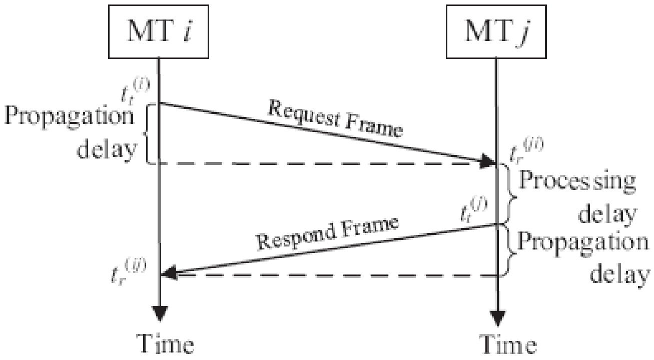

Fig. 2. TWR process

Assuming the propagation delays of the request and respond frames are the same, the distance between two MTs is: [7]

$$d^{(ij)} = \frac{1}{2}\left[\left(\frac{t_r^{(ij)} - t_t^{(i)}}{s^{(i)}}\right) - \left(\frac{t_t^{(j)} - t_r^{(ij)}}{s^{(j)}}\right)\right]c \qquad (1)$$

where $t_t^{(i)}$ is the transmitting time from MTi, $t_r^{(ij)}$ is the receiving time at MTj from MTi, s is the clock skew, c is the light speed. Notice that this distance is measured by MTi, if MTj needs the measurement, another round of TWR frames is needed.

ii. CO-MWR

In order to meet performance requirements, other distance measurement algorithms have been studied. CO-MWR (CrossOver Multiple-Way Ranging) was mainly designed to minimize resources while maintaining good performance [6].

CrossOver Multiple Way Ranging is a communication technique used in satellite navigation technology. It is based on the simultaneous transmission of multiple ranging signals to and from the receiver, allowing for the calculation of more accurate and reliable position, velocity, and time (PVT) data. This method uses multiple reference stations and multiple satellites to determine the receiver's position, typically in three-dimensional space. CrossOver Multiple Way Ranging is used in many navigation systems, such as the Global Positioning System (GPS) and the GLONASS system.

According to figure 3, its operation is based on the sending of "CrossOver Frame (CF)" periodically and simultaneously by all the nodes. Assuming that the timing is not absolutely perfect, it also causes a time offset called "time offset". These shipments are synchronized with techniques used in GNSS, in particular

1PPS (1 Pulse Per Second). At each period, the determination of the distance between terminals MTi and MTj are defined by equation 2.

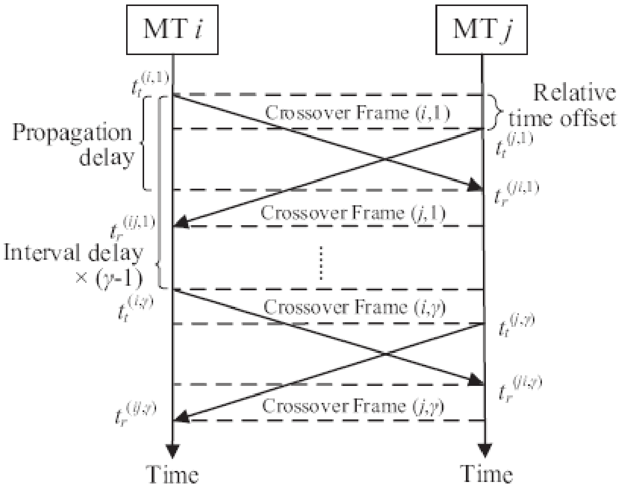

Fig. 3. CO-MWR process

After receiving the CFs, MTs do not respond immediately. They will wait for a known interval delay Δ_t and then transmit another CF. Then, the distance between two MTs in CO-MWR is calculated as [7]:

$$d^{(ij)} = \left[\left(\frac{t_r^{(ij,y)} - o^{(i)}}{s^{(i)}}\right) - \left(\frac{(y-1)\Delta_t - o^{(j)}}{s^{(j)}}\right)\right]c$$
$$d^{(ji)} = \left[\left(\frac{t_r^{(ji,y)} - o^{(j)}}{s^{(j)}}\right) - \left(\frac{(y-1)\Delta_t - o^{(i)}}{s^{(i)}}\right)\right]c \qquad (2)$$

Where $d^{(ij)}$ is the distance between MTi and MTj measured by MTi, $t_r^{(ij,y)}$ is the instant of reception of node i from node j during the y-th period, s is the offset clock, c is the speed of light, y is the n-th period, Δ_t is the interval between each sending and o represents the offset.

iii. MDS and Clustered MDS

MDS (MultiDimensional Scaling) is a set of data analysis techniques that display data structures in a geometric figure. It uses one or more matrices of similarities such as the distance between objects and places in a space of 2 or 3 dimensions. This is the classical version of MDS.

It is a technique used to analyze relationships among objects based on their pairwise distances. It is a useful tool for cooperative localization, which is the estimation of the relative positions of multiple objects in an environment. MDS can be used to assess the accuracy of cooperative localization algorithms by visualizing the differences between estimated and true positions. Additionally, MDS can be used to develop new cooperative localization algorithms by analyzing the relationships between the objects and their estimated positions.

Cooperative localization can be performed if all the nodes of the network in question can have direct or at least indirect (multi-hop) communication. Multi-hop communications make it possible to build the distance matrix using so-called intermediate nodes. For this, some models rely on algorithms such as Dijkstra's algorithm.

The problem in an urban environment is that some nodes in the network may not be able to communicate due to various obstacles. To solve this, the nodes of the network can be separated into several zones or classes using the k-means or k-means algorithm for data partitioning. Then, we have Clustered MDS which is a technique that can be used to improve the accuracy and speed of cooperative localization. It works by clustering nodes in the network into groups, and then using the MDS algorithm to determine the positions of the nodes in each cluster. This allows for faster convergence times and more accurate localization results. Additionally, it helps reduce the number of nodes that need to be localized, reducing the amount of energy consumption required for cooperative localization.

PRIOR KNOWLEDGE

Localization systems

i. GNSS

GNSS (Global Navigation Satellite System) is a satellite system which provides signals from space to receivers which then use this data to determine location. The most popular GNSS system is undoubtedly the GPS (Global Positioning System).

GPS has good precision, particularly due to a very precise atomic clock; however, its availability is limited by several parameters such as the number of accessible satellites with GDOP (Geometric Dilution Of Precision) or the direct visibility towards them. It is often unusable in indoor environments [1].

ii. Network-based localization

This localization system uses antennas as references. almost everyone already has a mobile terminal and is thus potentially able to access location-based services based on this mobile network.

Mobile networks of any generation have a system for positioning their subscribers. In this case, the references (RP) are the base stations. The techniques used are numerous such as Timing Advance, Cell-ID, TOA (Time Of Arrival), AOA (Angle Of Arrival), E-OTD (Enhanced Observed Time Difference).

Compared to GPS, network-based localization offers poorer accuracy. However, it has some advantages, such as the possibility of indoor localization.

5G Network

i. Definition and characteristics

It is expected that 5G will be unlike previous generations. The major differences will not be merely combinations of old and new radio access technologies; 5G will also enable new use cases and requirements of mobile communication beyond 4G systems. It will be an integration of existing cellular standards and technologies, including new disruptive technologies like mmWave and spectrum sharing [2].

ii. 5G and Localization

With a sufficiently precise location, the 5G network will be the first to benefit greatly from location information. Indeed, this information is not only intended for the operation of location-based services (LBS) but it can also respond to certain challenges of 5G. Here are some localization contributions on the performance of 5G [3]:

- Loss of propagation: The power received decreases as the distance increases. Accurate knowledge of position and distance determines the optimal transmitting power. Thus, the choice of BS is also optimal.

- Fading: This occurs when the propagation channel is obstructed by obstacles. The multiple communications between the nodes make it possible to know the CSI (Channel State Information) in numerous zones.
- MIMO Beamforming: The beams are formed by antennas oriented towards a precise direction. A wrong estimate of the orientation angle considerably degrades the QoS measurements. Thus, the location makes it possible to acquire the position, the distance and especially the angle of orientation towards the desired destination.
- Propagation delay: The propagation delay can be acquired by dividing the estimated distance and the propagation speed of the location signal.
- Doppler effect: The speed estimated from a precise localization sequence makes it possible to determine the Doppler deviation of the received signal.

iii. Benefits of localization in 5G

a. Wide bandwidth

5G will use frequency bands higher than 24 GHz, which allows for the creation of a large bandwidth. Millimeter waves increase the accuracy of TOA techniques. This also causes 2 impacts on the location. On the one hand, a large bandwidth allows better resolution of delay spreading problems, so that multiple paths can be more easily estimated. On the other hand, a very high frequency carrier reduces diffraction [4].

b. Many antennas

With MIMO technologies, 5G uses multiple antennas for transmission. Increasing the number of antennas improves the determination of arrival angles (AOA) and departure angles (AOD). This also improves the resolution of problems in the spatial domain, in particular the precision in the estimation of multipaths. Thus, even with a single reference, the localization performance is greater [5].

c. Network densification

To increase radio coverage and cope with insufficient capacity, operators are setting up new base stations. Thus, the densification of the network leads to a densification of the Base Stations (BS). We can therefore take advantage of a shorter distance between the transmitter and the receiver.

d. D2D communication

Since LTE release 12, D2D communication is considered a potential candidate for proximity detection. In 5G, D2D communication will be native and will allow nearby terminals to communicate while reducing propagation attenuation, transmission power or even latency.

TOOL AND TEST RESULTS

Tests descriptions

In order to group and facilitate all the simulations carried out, we developed our own application.

We chose to use the WINNER + (Wireless World Initiative New Radio) propagation model which is the evolution of the WINNER I and WINNER II models. It is applicable for frequencies between 2GHz and 6GHz. The 3GPP Channel Model has also been studied because it can model transmissions with a frequency ranging from 0.5GHz to 100GHz.

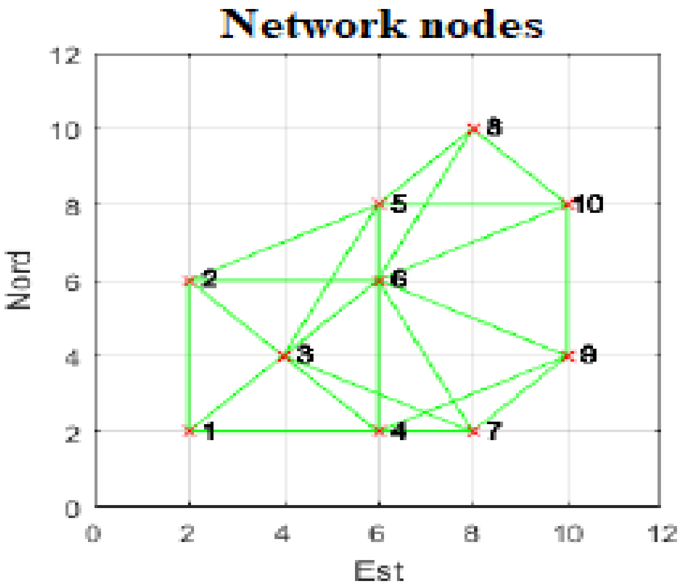

Fig. 4. Nodes

According to the figure 4, we use 10 terminals (nodes) which are randomly distributed on a 120m x 120m map with modifiable simulation parameters.

Tests and Performance Metrics

In order to assess the localization system proposed for 5G, we will study the relevant values. To better understand these valuation methods, we also need to know the theory of estimators in statistics.

In fact, these values are numerous: Cramer-Rao Lower Bound (CRLB), standard deviation, Root Mean Squared Error (RMSE), Connectivity length, Max error, Average error or Stress Function.

– RMSE [9]:

$$\mathrm{RMSE}(\hat{\Theta}) = \sqrt{MSE} = \sqrt{\mathrm{E}(\hat{\Theta} - \Theta)^2} \quad (3)$$

Ô is the estimator and Ө the unknown value to estimate.

– Stress function [10]:

$$S(X_1, \ldots, X_N) = \frac{1}{2} \sum_{l=1}^{N} \sum_{q=1, l \neq q}^{N} [\delta_{l,q} - d_{l,q}(X_l, X_q)]^2 \quad (4)$$

$\delta_{l,q}$ represents the estimated distance between nodes l and q and $d_{l,q}(X_l, X_q)$ is the real distance between two nodes whose coordinates X_l, X_q are unknown.

All the following simulations can be launched via our tool by clicking on the various buttons and tabs:

– We are going to show the effects of frequency on the PathLoss. Remember that 5G can use frequencies up to 52.6GHz. Thanks to the densification of the network, 5G terminals are also closer and the distances between them are shorter

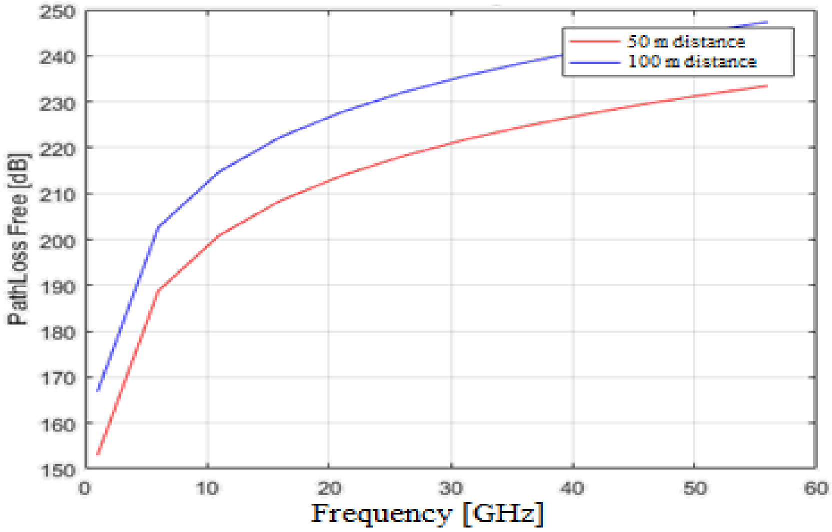

Fig. 5. Path Loss as function of frequency and distance

Unfortunately, it has been found that the use by 5G of a frequency SHF (3 to 30 GHz) and EHF (30 to 300 GHz) causes an increase in the value of the PathLoss. However, it decreases proportionally with the distance between the transmitter and the receiver.

- The following figure 6 illustrates the effect of a signal with a large bandwidth on the accuracy of localization based on TOA

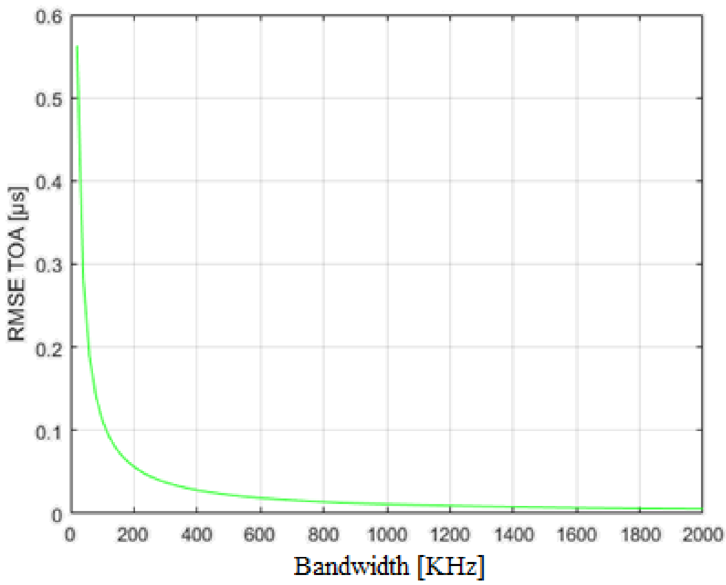

Fig. 6. RMSE as a function of signal bandwidth

For TOA-based techniques, we observed that the larger the bandwidth, the greater the reduction in Root Mean Square Error (RMSE). Consequently, our location system based on TOA will be highly beneficial given that the 5G network utilizes waves with a bandwidth of more than 50MHz.

- We will now compare the TWR and CO-MWR cooperative algorithms to perform our cooperative localization

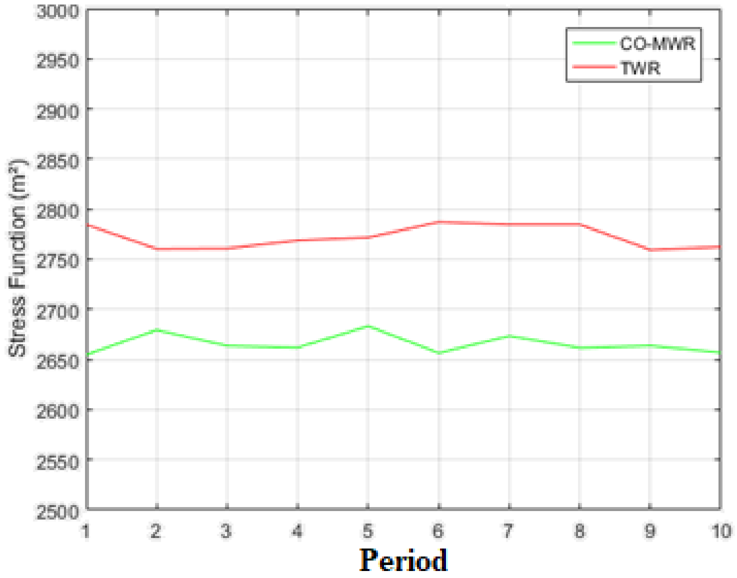

Fig. 7. Stress function as a function of y-th period

The figure 7 demonstrated that the CO-MWR curve (green curve) is always below the TWR curve (red curve). Therefore, we can conclude that the utilization of the CO-MWR algorithm results in less difference between the actual distance and the estimated distance between the nodes.

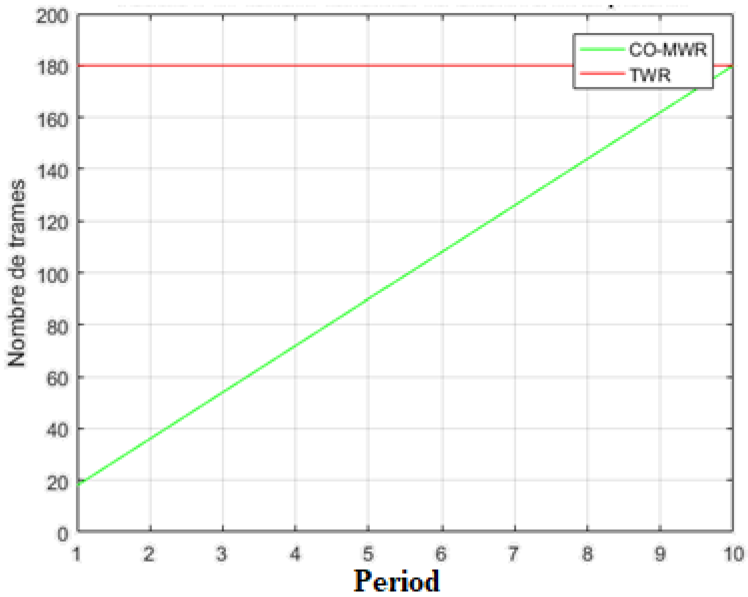

Fig. 8. Number of frames as a function of y-th period

On the one hand, the TWR algorithm requires the use of 2N (N-1) frames where N is the number of terminals. On the other hand, the number of frames used by CO-MWR depends on the number of periods during cooperative localization. It's 2i (N-1) where i is the index for the current period.

Thus, CO-MWR algorithms are more efficient than TWR algorithms in terms of accuracy and resource consumption

– Relative map generation with Classical MDS

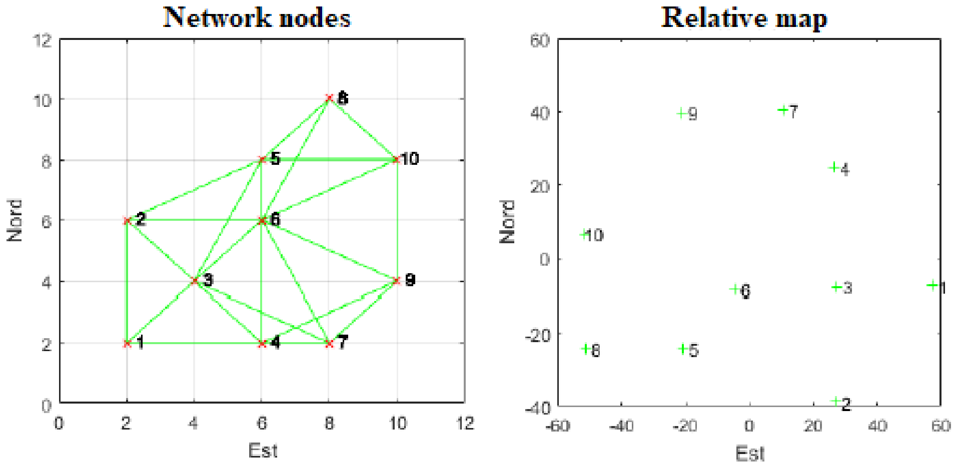

Fig. 9. Relative map with classical MDS

Note that with this relative map, the positions of each node are obtained with a new orientation and a more precise distance. Therefore, we can use nodes whose coordinates are known to obtain an absolute position map.

– Maps generation with Clustered MDS

Now, we'll make the previous test with the Clustered MDS. This time, we are going to arrange 20 nodes as shown in the figure. With k=3 clusters, this algorithm builds 3 maps.

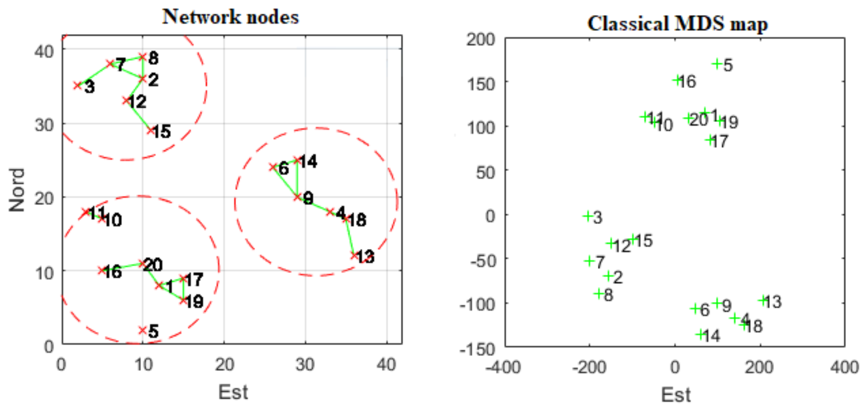

Fig. 10. Classical MDS map

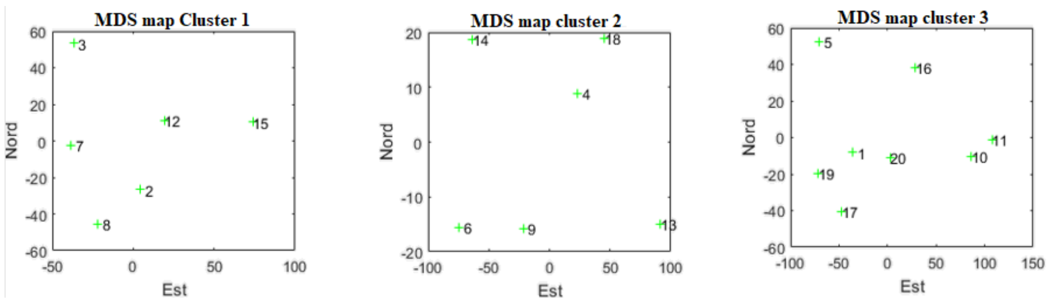

Fig. 11. Relative maps with Clustered MDS

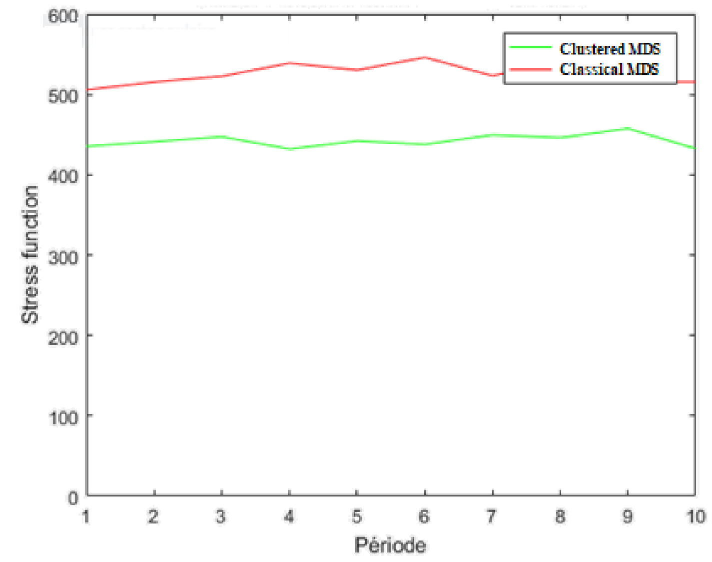

Fig. 12. Stress function between the two versions of MDS

We can see that the Clustered MDS offers better accuracy because its Stress function is always below that of the Classic use of MDS over 10 test periods.

MOTIVATION AND DISCUSSION

First of all, we absolutely want to demonstrate the advantages of using cooperative localization instead of traditional localization in 5G networks. It uses more complex algorithms but the results are satisfactory. We saw that we could improve our accuracy by carefully selecting the algorithms and techniques to use.

Most of the time, applications of localization mainly seek to use GNSS. This is due to the lack of precision of localization in previous generations of mobile networks. Another objective is to motivate large applications to use mobile networks and lessen the reliance on the satellite system which can be inaccessible under certain conditions.

CONCLUSION AND PERSEPCTIVES

This article focuses on the area of localization which is constantly evolving. We explained the classical method but especially the new concept of cooperative localization based on multiple D2D communications. We observed that it's very beneficial for the localization system of 5G mobile network. By varying the simulation parameters, our tool allowed us to compare the performance of some cooperative algorithms in a specific propagation model. We found that there are many algorithms that can be used in this localization process. We have seen the advantages of using CO-MWR and a clustered MDS.

As perspectives, we could apply COMWR to other types of networks because it now supports multiple data transmission protocols, including Bluetooth LE, Wi-Fi.

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