Enhanced satellite positioning methods using ultrawideband D2D-based localization for ultra-dense 5G wireless setting

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Abstract. The drawbacks of legacy satellite positioning systems necessitate new procedures for high resolution location services. Moreover, location-aware devices, systems and networks are critical for 5G/future network setting that seeks to seamlessly connect global devices in an all-IP network. It is therefore believed that satellite positioning could be enhanced with impulse radio (IR) ultrawideband (UWB) localization approaches for accuracy-critical situations expected in 5G wireless. This paper presents results of research on enhanced satellite positioning methods for ultra-dense 5G setting. The methods combine information from satellites, fixed wireless networks, wireless LANs and cellular communication along with global cloud databases. This is conceptualized as an IR-UWB device-to-device (D2D) overlay network that seamlessly incorporates satellite data into the 5G terrestrial network environment. A link to at least one satellite on the global positioning constellation would suffice for accurate localization. Also presented is the IR-UWB D2D-propagation-based combined localization and communication scheme (UD-CLOCS). The UD-CLOCS scheme transmits location and communication data in a single signal while performance evaluations have been impressive. It is believed that the solutions have potential for robust and cost-efficient satellite positioning as well as prospect to de-congest licensed spectrum in 5G wireless setting. The significance of the research outcomes is that satellite positioning signal and data could be seamlessly integrated into global 5G networks for enhanced positioning services as well as improved spectral efficiency.

1. Introduction
The 5G setting is envisaged as an all-IP seamless connection of global devices featuring gigabit data at less than 1ms end-to-end latency [1]. This would require high accuracy positioning schemes to perform better than legacy system in Figure 1; which requires at least three satellites on the GPS constellation for accurate position determination. Moreover, there are other drawbacks such as signal blocking effects in dense urban scenarios as well as harsh environments that affect legacy methods. There is thus the need for new schemes to enhance current satellite positioning systems in the 5G global network setting. Indeed, future wireless systems should possess seamless satellite positioning capabilities and IR UWB is considered to offer a promising alternative [2]. UWB technology capabilities such as robust communication in dense and multipath situations is considered suitable for enhanced satellite positioning applications in 5G wireless setting [3]. For location estimation purposes in this paper, the IEEE802.15.4a UWB localization enabled WPAN standards in [4] and [5] are adopted. The remaining sections highlight the UWB enhanced satellite positioning research along with performance evaluations.
2. IR UWB D2D-based enhanced satellite positioning
   2.1. Prospects of IR UWB D2D enhanced satellite positioning
   One of the challenges envisaged for the 5G environment is high accuracy satellite-based positioning due to expected ultra-dense setting. An IR-UWB network overlay is therefore conceptualized as highlighted in Figure 2 to address the need. The scheme localizes devices in a D2D fashion such that satellite is seamlessly incorporated with terrestrial communication systems while taking advantage of global positioning information on cloud databases. Also proposed as a complement enhancement for satellite positioning in ultra-dense 5G network setting is the IR UWB D2D-propagation-based combined localization and communication scheme (UD-CLOCS). The concept features wireless wide area network (WWAN) with piconet as its smallest component comprising of discrete micro-channel slots (DMCS). The method is a low system-load network and devices can join a cluster and update position estimate by executing a mathematical local cost-function. Additionally, the system also addresses key 5G prospects like higher device densities, smaller cells and globe-wide D2D cooperative positioning. Simulation results suggest D2D distribution with capacity to support a very high density of connected devices per square meter of urban environments as those expected in large-scale 5G/future networks.

3. UD-CLOCS IR-UWB WWAN for satellite positioning
   3.1. Structure of the UD-CLOCS IR-UWB WWAN setting
   The most important component of the UD-CLOCS IR-UWB WWAN piconet is the piconet coordinator (PNC). This comes with connected devices and data is shared in peer-to-peer (P2P) mode and is managed by the PNC in line with IEEE 802.15.3 standards in [6]. The PNC has basic timing as its major function as well as management of network resources. However, in the UD-CLOCS D2D WWAN, the piconet is IR-UWB-based which frees-up the licensed spectrum. It should be noted that each DMCS acts as separate channel used by any 2 devices in D2D connection. As shown in Figure 3, the DMCS is composed of three parts. These are: the channel time allocation period (CTAP), the beacon period (BP) and the channel access period (CAP). Simulation experiments suggest that the DMCSs possess enough UWB bandwidth. This therefore addresses the problem of in-band concurrent user interference as well as capacity to increase channel throughput. The observed effect on throughput is significant for satellite signal injection into ultra-dense 5G environment.

4. UD-CLOCS IR-UWB cluster for seamless satellite location services
   4.1. Formation of cluster in a UD-CLOCS IR-UWB setup
   The IR-UWB D2D communication overlay has the capacity to enhance satellite positioning methods along with improved spectral efficiency and reduced end-to-end latency in 5G setting. Earlier attempts at D2D communication in cellular network focused on distributed scheduling. Methods include [9] and...
many others like IEEE 802.11 protocol stack [10] as well as bluetooth and wifi-direct (Wifi-P2P). All were geared towards D2D connections that are efficient and effective in unlicensed bands such that also bypasses access points in a wireless environment [11]. The focus was to use radio technology for short range, low power as well as low cost wireless communication [12]. However, all these methods utilize different transmissions for the in-band and the out-band scenarios. Specifically, UD-CLOCS WWAN D2D features full–duplex IR-UWB communication within the same UWB band. This covers both communication and localization data transfers in the same signal band allocated for specific D2D link.

4.2. Satellite positioning cluster formation structure for UD-CLOCS IR-UWB scheme

Figure 4(a) highlights the UD-CLOCS D2D cluster formation scenario. A base station (BS) and a high density of relay stations (RS) deployments denoted as RSa, RSh, RSc, ..........RSh+1. Also included are hypothetic clusters of many devices designated Da, Db, Dc ..........Dn, Dn+1.nAll devices use IR-UWB interface for data transfer. Mobile devices have restricted battery power. Therefore, it is important to fashion a scheme that reduces power consumption while also agreeing with [13] regarding standard requirements for cluster, cluster head (CH) and cluster normal member (CNM). The considered devices are also able to determine their residual charge as well as signal-to-interference-plus-noise ratio (SINR). Moreover, the devices come with embedded respective WiFi, cellular and IR-UWB interfaces. Clusters
additionally, have corresponding CH that is able to determine all of the CNMs’ intent values (IV); while time is synchronized with the CH via the UD-CLOCS IR-UWB interface. Figure 4(b) details the cluster formation scheme for UD-CLOCS WWAN D2D IR-UWB. The procedure allows a new user/device \( T_{\text{new}} \) to initiate a D2D communication by a process of scan, detect and analysis of the joining instructions broadcasted by a CH periodically.

4.3. Satellite positioning cluster head transfer for UD-CLOCS scheme

A CH selection and transfer method is proposed bearing in mind limited cluster lifetime and system capacity. This combines the normalized residual charge of each CNM denoted as \( R_{\text{CHG}}^{\text{Nom}} \) with normalized SINR denoted as \( S_{\text{Nom}} \) such that the following are defined:

- IV - CH updating rank variable.
- \( \alpha \) - \( S_{\text{Nom}} \) weighted factor.
- \( R_{\text{CHG}}^{\text{Nom}-1} \) - CNM residual charge when it becomes CH.
- \( R_{\text{CHG}}^{\text{Nom}-2} \) - CH current residual charge.
- IVCH – current CH intent value such that Equation (1) is true.
- \( T_{\text{xpt-max}} \) - UD-CLOCS IR-UWB WWAN D2D cluster maximum throughput.
- B - cumulative channel bandwidth of all DMCSs for cluster members D2D interchange.

\[
IV = \alpha \times S_{\text{Nom}} + (1 - \alpha) \times R_{\text{CHG}}^{\text{Nom}}
\]

A maximum SINR denoted as \( \text{SINR}_{\text{max}} \) applies for cluster members. Therefore, \( T_{\text{xpt-max}} \) could be expressed as shown in Equation (2) in accordance with Shannon’s theorem. Hence, at specific given slots, each CNM sends its SINR and residual charge to the CH. The CH in-turn compares all received SINR with \( \text{SINR}_{\text{max}} \) and selects \( \alpha \) according to Equation (3) based on set parameters. Moreover, the CH calculates all the CNMs’ IV to obtain the highest IV denoted IV\(_{\text{max}}\). This enables selection of CNM with IV\(_{\text{max}}\) as the CH at the next step in accordance with Equation (4); else the CH continues to perform above actions which ensures extended cluster lifetime. Additionally, simulation results suggest that the process does not degrade UD-CLOCS WWAN throughput. Conversely, in a Wi-fi-based D2D, transmission between CH and CNMs are carried out with synchronized time reference via the WiFi-Direct interface using licensed spectrum [14]. Moreover, most of previous works on in-Band D2D communication focused mainly on resource allocation and interference from D2D users to the cellular networks [15].
However, UD-CLOCS IR-UWB D2D WWAN adjacent cluster cooperation contains all transmission within the allotted UWB band which is most significant. UD-CLOCS IR-UWB D2D WWAN therefore most probably offers a more efficient alternative in this circumstance.

\[ T_{\text{xpr-max}} = \log_2(1+\text{SINR}_{\text{max}}) \quad (2) \]

\[ \alpha \in [0, 1], S_{\text{Nom}} \in [0, 1], \]

\[ \text{R-CHG}_{\text{Nom}} \in [0, 1] \quad (3) \]

\[ \text{IVCH} \leq \text{IV}_{\text{max}} \quad (4) \]

5. UD-CLOCS Performance evaluation

5.1. UD-CLOCS cluster lifetime in comparison with number of active cluster members

This section presents evaluation of UD-CLOCS IR-UWB D2D WWAN cluster lifetime as against number of cluster members. It assumes that all cluster devices have the same charge and that the SINR follows a random distribution pattern. It further assumes that the SINR is constant for each CNM during the entire period of simulation. As results in Figure 5(a) indicate, for varying values of \( \alpha \) (the weighted factor to the \( S_{\text{Nom}} \)); the mean lifetime of the cluster increases as the number of CNMs is increasing. Therefore, the cluster lifetime remains a constant value notwithstanding the growing number of CNMs. Nevertheless, UD-CLOCS IR-UWB D2D WWAN cluster scheme addresses low power scenario with the inequality expression in Equation (5). It very significant that increasing number of cluster members no matter the value of \( \alpha \) results in increasing cluster lifetime for UD-CLOCS setting. This has potential to seamlessly accommodate satellite positioning signal and data into ultra-dense setting expected in 5G.

\[ 2 \left( \text{R-CHG}_{\text{Nom-2}} \right) \leq \left( \text{R-CHG}_{\text{Nom-1}} \right) \quad (5) \]

5.2. Comparison of system throughput for UD-CLOCS, standard cellular and wifi

This section highlights comparison of system throughput for UD-CLOCS IR-UWB D2D WWAN, cellular and wifi. A working bandwidth of 20MHz is assumed for the cellular network. This is divided into 2 links and the cell can accommodate 2 cellular users at most for data transfer to BS. Also, one CH can connect with 7 CNMs at most. For the wifi simulation, this paper agrees with [16] and [17] that posit maximum throughput of wifi-direct network at 250 Mbps. Simulation results in Figure 5(b) show that the UD-CLOCS IR-UWB D2D WWAN cluster cooperation scheme is able to increases the system

![Figure 5](image)

Figure 5 Performance of UD-CLOCS cluster lifetime and comparison of its throughput capability.
throughput significantly by a factor of about 0.75 in concert with increasing number of cluster devices. This suggests suitability of UD-CLOCS to enable high data throughput which not only enhances satellite positioning but has additional potential for seamless, low latency and effective satellite data distribution over terrestrial networks in the 5G setting.

6. Conclusion
This paper presents an IR-UWB D2D overlay network; UD-CLOCS that seamlessly incorporates satellite positioning signal and data into the 5G all-IP terrestrial global network. Results of simulation experiments suggest that performance of UD-CLOCS cluster formation scheme, its cluster lifetime and system throughput would significantly enhance satellite positioning in 5G setting. Future work on this research will focus on further field work on incorporation of satellite signals and data in ultra-dense setting along with its effect on network performance. This is with a view to enhancing satellite positioning in 5G/future network.

7. References
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