Ultra Dense 5G High Speed Network For Device Localization In Enabling Technology

SrihariChintha, Research Scholar , Department of Computer Science & Engineering, Sunrise University, Alwar, Rajasthan ,
Dr.SudhirDawra, (Supervisor), Department of Computer Science & Engineering, Sunrise University, Alwar, Rajasthan

Abstract—The deployment of future 5G ultra-dense small cell networks provides unprecedented opportunities to create an advanced localization system that meets the demands of future location-based services and functionalities. In this paper, we present technical enablers for obtaining location information of user nodes (UNs) in a network-centric manner. More specifically, we focus on signal properties, access node (AN) hardware and AN deployments in the envisioned 5G systems. Moreover, we provide illustrative examples of the expected localization performance and indicate how to efficiently predict the UN location. Finally, we offer insights into the utilization of location-awareness and location prediction, and show that it provides substantial benefits compared to existing radio networks.

Index Terms—5G networks, data fusion, localization, location-awareness, positioning, prediction, radio resource management, small cells, tracking, ultra-dense networks

I. Introduction

It is envisioned that future 5G networks will consist of access nodes (ANs) deployed with a very high spatial density, see e.g. [1], [2]. User nodes (UNs) in such ultra-dense networks are thus expected to operate under a coverage area of mul-tiple ANs simultaneously (see Fig. 1). This is beneficial for communication purposes by bringing communication endpoints closer together [3], but also enables accurate localization of UNs. Overall, the concept of ultra-dense small cells results in new opportunities and challenges to develop and provide localization in 5G networks which have, in general, many novel features compared to existing radio networks.

Recently, it has been proclaimed that 5G networks should be capable of localizing a UN with an accuracy in the sub-meter range [4, p. 31], [5], [6, p. 31]. This is clearly beyond existing systems. For example, the observed time difference of arrival (OTDoA) techniques used in long term evolution (LTE) provide an accuracy of a few tens of meters [7], while commercial global navigation satellite systems (GNSSs) have an accuracy

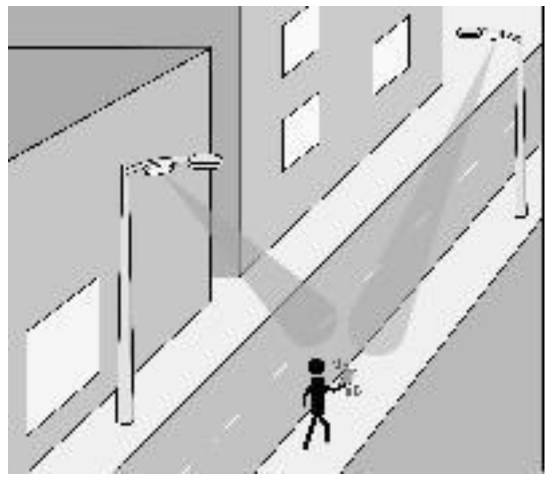

Fig. 1: Network-centric localization in an ultra-dense small cell network where ANs receive uplink pilot signals. The UN location is determined by fusing the measurements obtained at the ANs.

of around 5 m [8] and WLAN fingerprinting results in an accuracy of 3 – 4 m [9]. In addition to the enhanced accuracy, 5G localization techniques can offer improvements in terms of UN power consumption when utilizing network-centric localization based on frequently transmitted uplink pilot signals. It should be noted that localization does not need dedicated uplink signals but instead can exploit the uplink pilots that are in any case transmitted for channel estimation purposes [10]. Consequently, the power consumption requirements in the UNs for enabling localization are expected to be very low. This is an important and distinguishing feature compared to device-centric localization. In fact, future 5G UNs are expected to have improvements in energy efficiency in the order of 10x – 100x. Thus, network-centric localization services in ultra-dense networks can run in the background, and be able to provide high-accuracy location information at any time. Moreover, 5G localization may also be a solution for the challenging problem of indoor localization since it is not dependent on satellite connections and it is able to deliver reliable altitude estimates.

In general, localization in wireless networks is a widely-studied topic, see e.g. [11]–[16] and references therein. However, localization of UNs and using such an information in 5G ultra-dense small cell networks have not received significant attention. Therefore, in this paper we focus on the enabling tech-nologies of the envisioned localization systems in the 5G frame-work. In addition, we discuss how to exploit location-awareness and predicted UN locations in novel location-based services. In particular, we recognize that UN location information can be communicated to the UNs for navigation; used within the network for proactive radio resource management (RRM); and shared with third parties in order to provide location data for self-driving cars, among other examples. Finally, we provide five use cases where location-aware services and functionalities provide substantial benefits compared to existing solutions.

The rest of the paper is organized as follows. In Section II we list different options for acquiring UN location in ultra-dense networks, and provide key properties of 5G ultra-dense small cell networks. We also offer some insight for data fusion and location prediction which are of particular importance in location-based services and functionalities. In Section III, we fo-cus on the exploitation of the location information and give five examples highlighting the differences compared to conventional radio networks. Finally, conclusions are drawn in Section IV.

II. Obtaining UN Location in 5G Ultra-Dense Small Cell Networks

A. Measurements for Localization

The UN locations can be determined by multiple measure-ments. The UN-AN distance can be estimated from the received signal strength (RSS) of an uplink pilot signal with known trans-mit power by converting the resulting propagation loss into a dis-tance with the help of a path loss model [8]. Alternatively, such a distance can be estimated with the time of arrival (ToA) method which measures the propagation time of a signal from UN to AN [16]. Typically, such a method requires very accurate clock synchronization between the UN and AN [14]. However, such a strict synchronization may not be feasible and consequently ToA-based localization may become impractical. Similar tight synchronization requirements are not needed with the round-trip time of arrival (RToA) approach where the aggregated time used for short downlink + uplink transmissions is measured and the distance estimate is obtained via the speed of light [15]. Another approach is based on the time difference of arrival (TDoA) where the relative UN location is determined using the time differences between the reception of an uplink signal at different ANs [14]. The UN location can also be estimated based on directional information, i.e. direction of arrival (DoA) estimates, collected with smart antennas, i.e. antenna arrays or reconfigurable antennas, deployed at the ANs [13].

B. Properties of Ultra-Dense Networks

The inter-site distance of ANs in ultra-dense small cell net-works is expected to range from a few meters (indoors) up to 50 m (outdoors) [18]. Therefore, it is expected that UNs will be in line of sight (LoS) condition to one or a few ANs, see Fig. 2. Furthermore, 5G ANs are expected to be equipped with smart antenna solutions, such as antenna arrays or reconfig-urable antennas. On the one hand, antenna arrays in 5G ANs

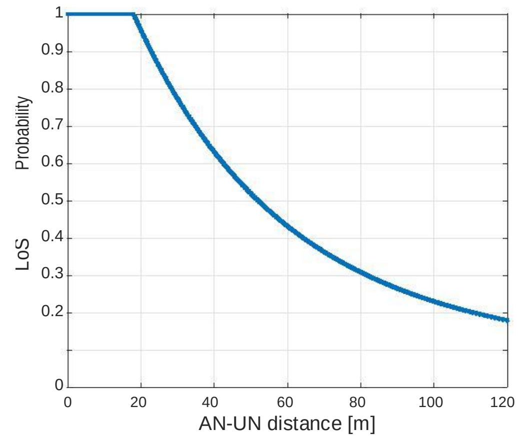

Fig. 2: Line of sight (LoS) link probability according to the 3D-urban micro propagation environment scenario of the METIS channel model [17]. Note that having a square grid with a maximum AN-AN distance of 50 m results in a maximum AN-UN distance of only 35 m.

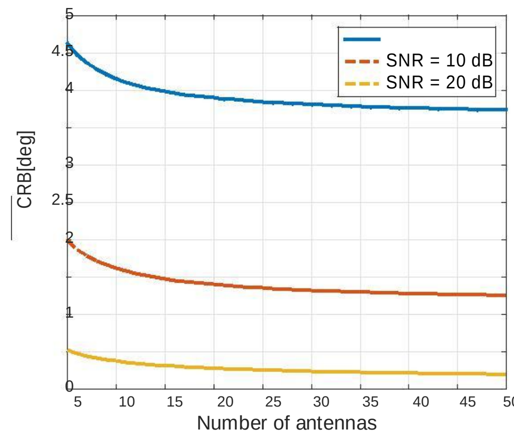

Fig. 3: Cramer-Rao bound (CRB) on azimuth DoA estimation as a function of the number of antenna elements in a circular array. The number of data samples used for DoA estimation is set to 100.

are foreseen to support massive multiple-input multiple-output (MIMO) type of communications where the number of antenna elements in ANs is significantly higher than the number of spatially multiplexed UNs [19], [20]. The lower bound on DoA estimation, namely the Cramer-Rao bound (CRB) based on the results in [21], as a function of the number of antennas is illus-trated in Fig. 3. The results show that large antenna arrays enable increasingly high accuracy on DoA estimation and therefore are beneficial in localization systems. On the other hand, ANs can also be equipped with reconfigurable antennas which have been shown to be suitable for DoA estimation and localization, e.g, in [22], [23]. In addition to physical structures, it is commonly agreed that 5G technologies will require high bandwidths in order to fulfill future capacity requirements. It is stated in [20] that at microwave frequencies the existing cellular bandwidths can, at best, be only doubled. Therefore, it is likely that 5G communications will operate at higher frequencies, including also millimeter waves (mmWaves), where the availability of free spectrum is substantially higher but the propagation losses are

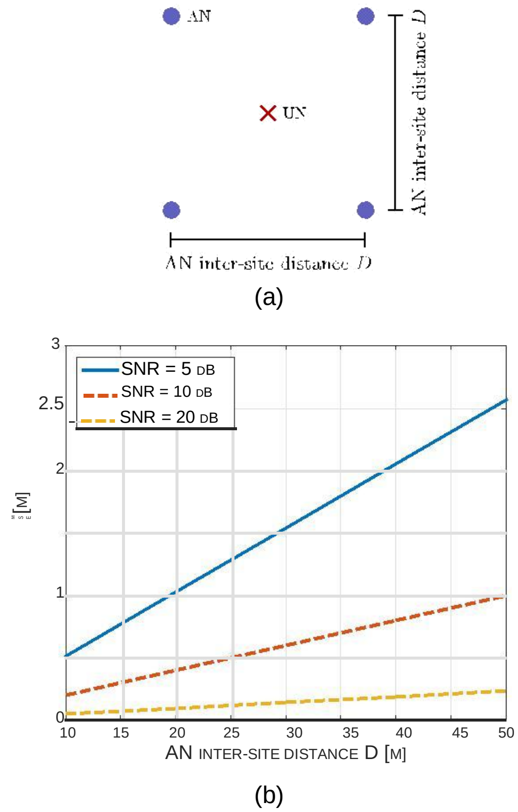

Fig. 4: Fusion of DoA estimates: (a) localization geometry, (b) Cramer-Rao bound (CRB) on the localization root-mean-squared error (RMSE) (1) as a function of the inter-site distance. The number of antennas is set to 10 while the remaining parameters are the same as in Fig. 3.

more severe than those at sub-6 GHz [18]. High bandwidths enable also very accurate ToA estimates [8] which in turn provide an opportunity for localization with very high accuracy. High frequencies, in turn, make the utilization of smart antenna solutions more practical due to the shorter wavelengths and consequently smaller physical size of the individual antenna elements [14]. Additionally, small cell networks are expected to operate in combination with a radio frame whose length is in a range of 0:1 ms – 0:5 ms [10], [15], [16]. Such a frame includes also uplink reference symbols (required for channel estimation) that can be used for network-centric localization, and consequently enable accurate and fast localization being able also to frequent location updates. To summarize, 5G ultra-dense small cell networks are well-suited for high-accuracy network-centric localization.

C. Fusion, Tracking and Prediction

Once the ANs have acquired one or multiple of the measure-ments discussed in Section II-A, these measurements have to be fused into a UN location estimate. For high-accuracy, this fusion process should be collaborative, taking measurements from multiple ANs into account [16]. As an illustrative example, consider the fusion of DoA estimates obtained at four ANs. For simplicity, assume a geometry as depicted in Fig. 4(a) where the UN is located in the center of the ANs. Furthermore, assume a normally distributed DoA estimation error with standard de-viation (STD) '. Due to equal distances from the UN to all ANs, the STD is also modeled as equal at all four ANs. Taking the well-known Fisher information matrix (FIM) for DoA-only localization (c.f. [28]) as a starting point, the CRB on the root-mean-squared error (RMSE) of DoA-only based localization is then obtained through straightforward calculations as

$$\mathrm{RMSE} \geq \sqrt{\mathrm{CRB}_x + \mathrm{CRB}_y} = \frac{D\sigma_\varphi}{\sqrt{2}} \qquad \text{....... (1)}$$

whereD is the AN inter-site distance. Fig. 4(b) depicts an evaluation of the localization CRB using the square-root of the CRB in Fig. 3 as the STD in (1). For realistic results we have chosen a moderate number of ten antennas. Despite the simpli-fying assumptions that we have made, the results in Fig. 4(b) have two important implications. First, densification directly increases the network's localization capabilities. Second, ultra-dense networks seem capable of very precise UN localization with an accuracy that may very well be below one meter.

By combining different types of measurements such as RToA and DoA, it is even possible to obtain a UN location estimate individually at a single AN [17]. In general, combining different types of measurements results in better performance, even in collaborative fusion systems [17], [18]. Furthermore, it is bene-ficial to track the location of a UN instead of localizing the UN anew whenever new measurements become available. Tracking is often implemented using Kalman filters. In Kalman filters, each iteration consists of a prediction step and an update step. By simply iterating the Kalman filter without executing the update step, it is thus possible to obtain an n-step prediction of the UN location in a convenient and efficient manner.

Fig. 5 illustrates an example of UN tracking in ultra-dense networks. The tracking is based on the fusion of DoA and ToA estimates using an extended Kalman filter (EKF). In order to utilize the ToA estimates, the joint DoA/ToA EKF does not only estimate the UN location but also the clock offset between the AN and UN device. Further information including video material can be found online at www.tut.fi/5G/VTC15 and in [17].

III. Prospects of Location-Awareness

Completely new location based services can be provided in fu-ture ultra-dense networks due to the high localization accuracy, fast movement tracking and location prediction. In general, such services can be classified into external and internal. In external services, the location information is shared with third parties which can use it for collision-avoidance in self-driving cars, street traffic monitoring and advertising, just to name a few. In-ternal services, in turn, include sharing the location information with the UNs. This enables navigation with extremely low power consumption as well as without the need for satellite visibility or fingerprinting databases. Location-awareness can also be used in the network side for enabling enhanced utilization of the radio resources in time, space, and frequency, including effective interference mitigation. The prediction of the UN locations can, in turn, increase the throughput of high-mobility UNs (using ge-ometric beamforming) and enable proactive RRM resulting, e.g., in power and latency optimized end-to-end communications.

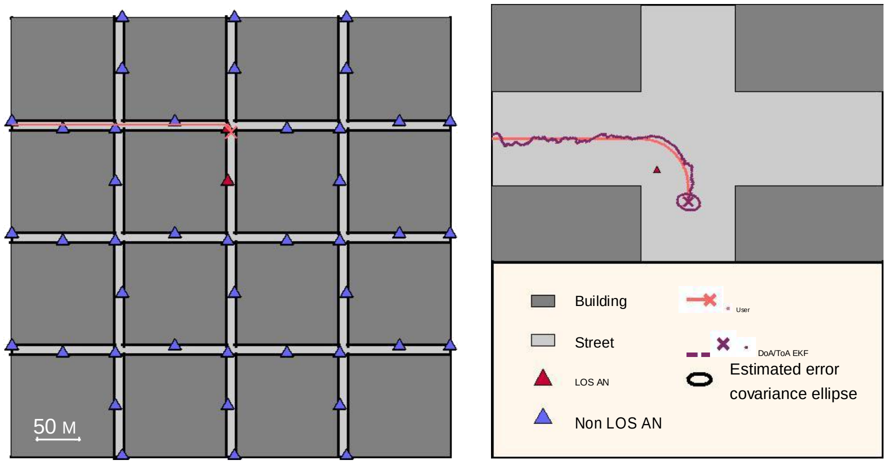

Fig. 5: Tracking example with a joint DoA/ToA extended Kalman filter (EKF) in an ultra-dense network [17].

In the following, we present in detail some of the prospects provided by the localization in ultra-dense small cell networks. 1) Content prefetching: The network can be assumed to know, to some extent, its coverage, capacity and the instanta- neous load of each AN. Consequently, using the predicted UN location and trajectory, the network is able to carry out proac-tive content delivery. This so-called content prefetching [19] becomes practical, e.g., in a case where a person is streaming a video over the internet while on a car which is approaching a cell with congestion. Normally, the user would experience a poor quality of service (QoS) or even lose the connection due to unavailability of resources. However, since the drop in the performance can be predicted, the network can prioritize the UN when it is still under the cell with free resources and thus proactively deliver content to a buffer in the UN. Consequently, the user can watch the video from the buffer while being in poor radio conditions and continue streaming from the internet after passing through the congested cell.

2) Radio environment maps (REMs): Accurate location information can be combined with average, large-scale fading radio conditions experienced in the ANs and UNs for generating high precision REMs [30]. In this way propagation losses between the ANs and UNs can be mapped to their physical locations, for example. Such a map, in turn, enables new possibilities for highly sophisticated spatial interference suppression since the beams of the smart antennas in the ANs and even in the UNs can be steered in such a way that the response to the desired directions is maximized while the interference to/from the undesired direction is minimized.

3) Proactive RRM: The combination of the REMs and pre- truck, based on the movement of a UN in the truck or observed directed UN locations provides interesting opportunities for RRM changes in the REM, which would most probably act as an without knowing the actual instantaneous channel information obstacle when coming between UNs and the associated AN. between the UN and AN. Consequently, location-awareness the available network resources can also be used to proactively allocate orthogonal radio resources such as frequencies, time slots and codes to the UNs. It should be noted, however, that predictive RRM functionalities require a guaranteed localization of all UNs since even a single lost or falsely located UN might cause difficulties to the network. Such a lost UN may, e.g., be unaware of the required communications parameters and thus interfere other nearly located UNs with too high transmit powers. It can also cause difficulties for the network functionalities since the network would not be able to do proper scheduling nor ensure fairness in the UN allocation anymore. Therefore, in order to ensure the desired QoS, proactive RRM functionalities require high quality of positioning service (QoPS). In practice,this means that the network needs to be highly robust against possible malfunctions and also ensure the required level of synchronization between network elements in all conditions.

4) Routing in the backhaul: Although the traditional idea of cells might not apply as such for ultra-dense small cell networks, the downlink data from the core network still needs to be forwarded to one or multiple ANs in a

certainarea before finally transmitted to the UNs. In order to provide seamless experience for the network users without the need for paging, the data should be available from ANs which have good visibility to the UNs. This could be challenging, especially, if utilizing mmWaves which are extremely vulnerable to shadowing due to obstacles. However, location-awareness and the predicted among other things, proactive allocation of the UNs to different experience. In addition to the proactive functionalities, routing ANs in such a way that desired metrics, e.g. power consumption becomes also much faster than in existing networks since the and load balancing, are optimized at the moment as well as in the paging messages, initiated by the core network, with long delays near future. The predicted locations and information regarding are not needed.

In the following, we present in detail some of the prospects provided by the localization in ultra-dense small cell networks.

1) Content prefetching: The network can be assumed to know, to some extent, its coverage, capacity and the instantaneous load of each AN. Consequently, using the predicted UN location and trajectory, the network is able to carry out proactive content delivery. This so-called content prefetching [29] becomes practical, e.g., in a case where a person is streaming a video over the internet while on a car which is approaching a cell with congestion. Normally, the user would experience a poor quality of service (QoS) or even lose the connection due to unavailability of resources. However, since the drop in the performance can be predicted, the network can prioritize the UN when it is still under the cell with free resources and thus proactively deliver content to a buffer in the UN. Consequently, the user can watch the video from the buffer while being in poor radio conditions and continue streaming from the internet after passing through the congested cell.

2) Radio environment maps (REMs): Accurate location information can be combined with average, large-scale fading radio conditions experienced in the ANs and UNs for generating high precision REMs [30]. In this way propagation losses between the ANs and UNs can be mapped to their physical locations, for example. Such a map, in turn, enables new possibilities for highly sophisticated spatial interference suppression since the beams of the smart antennas in the ANs and even in the UNs can be steered in such a way that the response to the desired directions is maximized while the interference to/from the undesired direction is minimized.

3) Proactive RRM: The combination of the REMs and pre- truck, based on the movement of a UN in the truck or observed dicted UN locations provides interesting opportunities for RRM changes in the REM, which would most probably act as an without knowing the actual instantaneous channel information allocate orthogonal radio resources such as frequencies, time slots and codes to the UNs. It should be noted, however, that predictive RRM functionalities require a guaranteed localization of all UNs since even a single lost or falsely located UN might cause difficulties to the network. Such a lost UN may, e.g., be unaware of the required communications parameters and thus interfere other nearly located UNs with too high transmit powers. It can also cause difficulties for the network functionalities since the network would not be able to do proper scheduling nor ensure fairness in the UN allocation anymore. Therefore, in order to ensure the desired QoS, proactive RRM functionalities require high quality of positioning service (QoPS). In practice, this means that the network needs to be highly robust against possible malfunctions and also ensure the required level of synchronization between network elements in all conditions.

4) Routing in the backhaul: Although the traditional idea of cells might not apply as such for ultra-dense small cell networks, the downlink data from the core network still needs to be forwarded to one or multiple ANs in a certain area before finally transmitted to the UNs. In order to provide seamless experience for the network users without the need for paging, the data should be available from ANs which have good visibility to the UNs. This could be challenging, especially, if utilizing mmWaves which are extremely

vulnerable to shadowing due to obstacles. However, location-awareness and the predicted

5) Localization in ultra-dense small cell networks combined with statistical UN mobility data may help to improve the localization and especially location prediction accuracy even further. It is reported in [26] that human mobility depends highly on historical behavior and is predictable up to 88 %. Therefore, based on the instantaneous location estimates, tracking and mobility databases, including e.g. the most common routes, the network could exploit machine learning type of algorithms to predict the UN movement more accurately and for a longer period of time.

IV. CONCLUSIONS

In this paper, we have presented an in-depth analysis of the properties that make 5G ultra-dense small cell networks very well-suited for network-centric UN localization, tracking and location prediction. In particular, we have studied proposals for antenna solutions, signal waveforms, network density, and radio frames with respect to their applicability to localization. Based on this study and supported by a CRB analysis we were then able to demonstrate the immense potential of network-centric UN localization in ultra-dense networks. Finally, we have provided five example use cases of UN localization, location tracking and location prediction. In these use cases we discuss examples of location-aware RRM and other proactive network functionalities that infer future network conditions from the predicted UN locations. Overall, we have shown that future 5G ultra-dense small cell network deployments provide unprecedented opportunities to create an advanced localization system that meets the demands of unforeseen location-based services and network functionalities.

REFERENCES

[1] A. Osseiran, F. Boccardi, V. Braun, K. Kusume, P. Marsch, M. Maternia, O. Queseth, M. Schellmann, H. Schotten, H. Taoka, H. Tullberg,M. Uusitalo, B. Timus, and M. Fallgren, "Scenarios for 5G mobile and wireless communications: The vision of the METIS project," IEEE Commun. Mag., vol. 52, no. 5, pp. 26–35, May 2014.
[2] Huawei, "5G: A technology vision (white paper)," 2013. [Online].Available: http://www.huawei.com/5gwhitepaper/P.
[3] Agyapong, M. Iwamura, D. Staehle, W. Kiess, and A. Benjebbour,"Design considerations for a 5G network architecture," IEEE Commun.Mag., vol. 52, no. 11, pp. 65–75, Nov. 2014.

[4] 5G Forum, "5G white paper: New wave towards future societies in the 2020s," Mar. 2015. [Online]. Available: http://www.5gforum.org/5GWhitePaper/5G Forum White Paper Service.pdf

[5] N. Wood, "Japan, Korea in 5G one-upmanship," Total Telecom, Jun. 2015.[Online]. Available: http://www.totaltele.com/view.aspx?ID=490150

[6] NGMN Alliance, "5G White Paper," Feb. 2015. [Online]. Available: https://www.ngmn.org/uploads/media/NGMN 5G White Paper V1 0.pdf
[7] J. Medbo, I. Siomina, A. Kangas, and J. Furuskog, "Propagation channel impact on LTE positioning accuracy: A study based on real measurements of observed time difference of arrival," in Proc. IEEE Int. Symp. Personal,Indoor and Mobile Radio Communications (PIMRC), Sep. 2009, pp. 2213–2217.

[8] D. Dardari, P. Closas, and P. M. Djuric,´ "Indoor tracking: Theory, methods, and technologies," accepted for publication in IEEE Trans. Vehicular Tech., 2015.

[9] N. Patwari, J. Ash, S. Kyperountas, A. Hero, R. Moses, and N. Correal, "Locating the nodes: Cooperative localization in wireless sensor networks," IEEE Signal Processing Mag., vol. 22, no. 4, pp. 54–69, Jul. 2005.

[10] G. Sun, J. Chen, W. Guo, and K. Liu, "Signal processing techniques in network-aided positioning: A survey of state-of-the-art positioning designs," IEEE Signal Processing Mag., vol. 22, no. 4, pp. 12–23, Jul.2005.
[11] H. Liu, H. Darabi, P. Banerjee, and J. Liu, "Survey of wireless indoor positioning techniques and systems," IEEE Trans. Syst. Man Cybern. C, Appl. Rev., vol. 37, no. 6, pp. 1067–1080, Nov. 2007.

[12] H. Wymeersch, J. Lien, and M. Win, "Cooperative localization in wireless networks," Proc. IEEE, vol. 97, no. 2, pp. 427–450, Feb. 2009.

[13] M. Win, A. Conti, S. Mazuelas, Y. Shen, W. Gifford, D. Dardari, and M. Chiani, "Network localization and navigation via cooperation," IEEE Commun. Mag., vol. 49, no. 5, pp. 56–62, May 2011.

[14] R. Baldemair, T. Irnich, K. Balachandran, E. Dahlman, G. Mildh, Y. Seln, S. Parkvall, M. Meyer, and A. Osseiran, "Ultra-dense networks in millimeter-wave frequencies," IEEE Commun. Mag., vol. 53, no. 1, pp. 202–208, Jan. 2015.

[15] C.-X. Wang, F. Haider, X. Gao, X.-H. You, Y. Yang, D. Yuan, H. Aggoune, H. Haas, S. Fletcher, and E. Hepsaydir, "Cellular architecture and key technologies for 5G wireless communication networks," IEEE Commun. Mag., vol. 52, no. 2, pp. 122–130, Feb. 2014.

[16] F. Boccardi, R. Heath, A. Lozano, T. Marzetta, and P. Popovski, "Five disruptive technology directions for 5G," IEEE Commun. Mag., vol. 52, no. 2, pp. 74–80, Feb. 2014.

[17] P. Stoica, E. Larsson, and A. Gershman, "The stochastic CRB for array processing: A textbook derivation," IEEE Signal Process. Lett., vol. 8, no. 5, pp. 148–150, May 2001.

[18] J. Werner, J. Wang, A. Hakkarainen, N. Gulati, D. Patron, D. Pfeil, K. Dandekar, D. Cabric, and M. Valkama, "Sectorized antenna-based DoA estimation and localization: Advanced algorithms and measurements," IEEE J. Sel. Areas Commun., 2015, accepted for publication.

[19] J. Werner, J. Wang, A. Hakkarainen, D. Cabric, and M. Valkama, "Performance and Cramer-Rao bounds for DoA/RSS estimation and transmitter localization using sectorized antennas," IEEE Trans. Veh. Tech., 2015, accepted for publication.

[20] N. Bhushan, J. Li, D. Malladi, R. Gilmore, D. Brenner, A. Damnjanovic, R. Sukhavasi, C. Patel, and S. Geirhofer, "Network densification: The dominant theme for wireless evolution into 5G," IEEE Commun. Mag., vol. 52, no. 2, pp. 82–89, Feb. 2014.

[21] P. Mogensen, K. Pajukoski, E. Tiirola, J. Vihrial¨a,¨ E. Lahetkangas,¨G. Berardinelli, F. Tavares, N. Mahmood, M. Lauridsen, D. Catania, and A. Cattoni, "Centimeter-wave concept for 5G ultra-dense small cells," in Proc. IEEE Vehicular Technology Conference (VTC Spring), May 2014.

[22] T. Levanen, J. Pirskanen, T. Koskela, J. Talvitie, and M. Valkama, "Radio interface evolution towards 5G and enhanced local area communications," IEEE Access, vol. 2, pp. 1005–1029, 2014.

[23] J. Werner, M. Costa, A. Hakkarainen, K. Leppanen,¨ and M. Valkama, "Joint user node positioning and clock offset estimation in 5G ultra-dense networks," in IEEE Global Communications Conference (GLOBECOM), 2013.

[24] J. Werner, A. Hakkarainen, and M. Valkama, "Cramer-Rao bounds for hybrid RSS-DOA based emitter location and transmit power estimation in cognitive radio systems," in Proc. IEEE Vehicular Technology Conference (VTC Fall), Sep. 2013, pp. 1–7.

[25] H. Abou-zeid and H. Hassanein, "Toward green media delivery: Location- aware opportunities and approaches," IEEE Wireless Commun., vol. 21, no. 4, pp. 38–46, Aug. 2014.