Enhancements for Enabling Point-to-Multipoint Communication Using Unlicensed Spectrum

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***Abstract*—Exponential increase in data rate demand has lead to the periodic upgrade of mobile network infrastructure, with a new generation of wireless access technology being developed every decade. Currently, the fifth generation (5G) of mobile networks – supporting higher data rates and reliability, with lower latency are being developed and planned to be deployed. Point-to-Multipoint or multicast / broadcast communication, which has received limited attention so far in 5G, enables the delivery of common content to a multitude of users, while consuming minimal amount of radio resources. In this work, we consider the usage of unlicensed spectrum for enabling such transmissions using enhancements of the currently specified LTE-Advanced eMBMS network. The proposed enhancements are fully compatible with distributed radio access network deployments, and require limited coordination between base stations. Using realistic 5G network assumptions, we also evaluate performance of such enhancements in delivering media content to a large number of users.**

I. Introduction

Multicast and broadcast (Point-to-Multipoint / PTM) communication enabled using the evolved Multimedia Broadcast / Multicast Service (eMBMS) feature [1], has been a key component in Third Generation (3G) and Fourth Generation (4G) LTE-Advanced (LTE-A) wireless networks, in enabling resource efficient content distribution [2]. The content has mainly been TV broadcast and public safety (public warning systems and mission critical communication systems) in legacy broadband networks. Due to the improvement in the content quality requirements and time criticality, the amount of radio resources consumed for delivering the content has constantly been increasing with the passage of time. The content quality requirements have been constantly increasing with advanced video and audio codecs enhancing the quality of experience of the end users, and the network operators need to allocate higher amount of radio resources to efficiently and effectively deliver this content to the end user. The scarce amount of available spectral resources makes such content delivery over the air, increasingly challenging, especially when the media is broadcasted over a wide area.

Current research focus on the 5G system and architecture design has been mainly related to traditional wide-area macro and ultra-dense small cell network deployments for media delivery using unicast [3], [4]. The implications on the radio access and core network for delivering PTM traffic using 5G has received limited attention in the past, both from academic and industry perspective. Recently, there has been an increasing focus on technologies that enable such communications with study items for the development of standards being discussed in 3GPP [5] and active research being done for developing technology enablers [6]–[8]. The use cases considered in [6] indicate the need for PTM communications to enable the efficient transport of data for a multitude of verticals apart from media and entertainment, such as - automotive, internet of things and public safety. The detailed performance benchmarking of 4G LTE-A Pro networks is done in [9], evaluating the need for enhancements in 5G. The overall content delivery framework required for such types of traffic is evaluated in [10]. For the media and entertainment vertical, the challenges for the mass delivery of virtual reality data which consumes significant amount of network bandwidth has been investigated in [11]. The use of device-to-device (D2D) augmented broadcast as a possible technology enabler addressing such challenges have been presented in [12].

Vertical micro-operator (μO) networks that can be deployed with minimal inter-working with the wide-area macro network operators is considered to be a key disruptor in 5G [13]. The μO networks enable the wider technology adoption of 5G networks, with its native support of services that require ultra-reliability and low-latency. The main advantage of such networks is the ability to tailor the network to specific use cases, thereby enhancing the quality of service and experience for the end users. A key enabler for such deployments would be its operational capability in unlicensed bands, in order to further reduce the deployment costs for μOs. The enhanced architecture and mechanisms considered in this work could be applied to any type of operator network deployed for provisioning PTM services.

One of the most important problem related to μO networks and PTM transmissions, is related to the setting up of spectrally-efficient single frequency network (SFN) [2] using unlicensed band deployments, while complying to the regulatory requirements of unlicensed band transmissions. This would be an important enabler for μO deployments using 5G-Xcast transmissions, and a key driver for the support of new verticals and use cases in 5G. Here Xcast implies an efficient mix of uni-, multi-, and broad- cast transmissions. There are a significant number of use cases for which such solutions would be relevant and important. The key issue here is the setting up of SFN in an unlicensed band, solutions for which currently does not exist. The main reason behind this has been the consideration of unicast service provisioning over

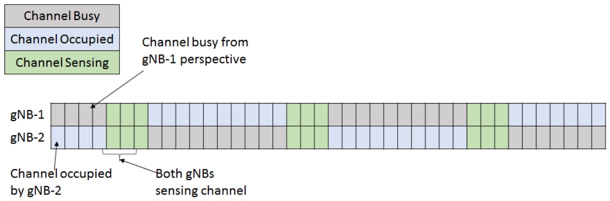

Fig. 1. Channel access for listen-before-talk.

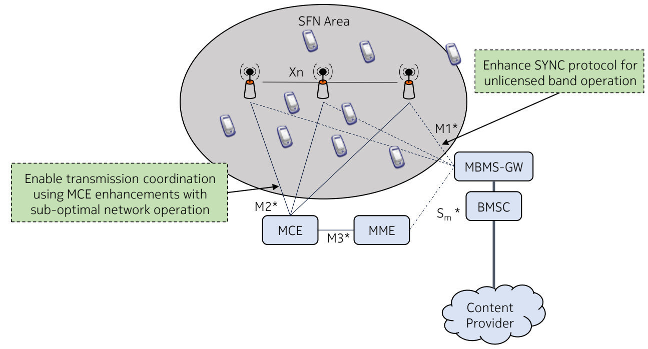

Fig. 2. System considered in this work.

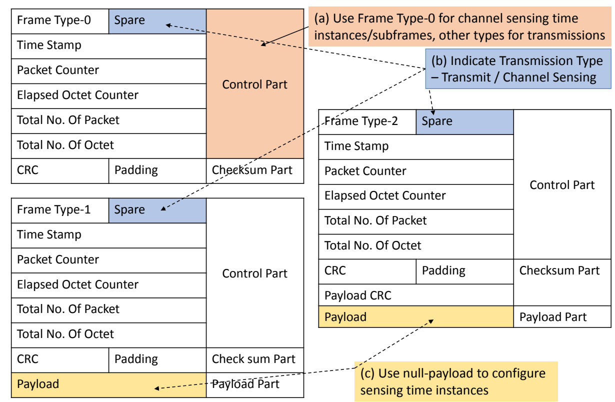

Fig. 3. Possible SYNC protocol enhancement options.

unlicensed bands.

Unicast transmissions using unlicensed band has received significant attention in the context of 4G networks. LTE operation using unlicensed spectrum with license-assisted access (LAA) feature which augments the capacity of existing deployments using licensed spectrum has been studied in [14]. The co-existence of LTE and WiFi, especially with the usage of Multefire standalone unlicensed network deployments have been considered in [15]. In order to obtain the significant amount of bandwidth required for 5G networks, they need to natively support unlicensed band operation [16]. Hence, the future releases of the standards are expected to support standalone operation using unlicensed frequency bands.

The challenge in operating SFN on unlicensed spectrum is that due to the listen-before-talk (LBT) mode of operation required by the regulations [17]: 1) the access to the medium cannot be guaranteed at any specific moment, and 2) even the other transmitters of the same network (SFN) block the access to the channel. Another key challenge is that the transmit power is limited on unlicensed spectrum leading to smaller cell size. Thus, there are potentially a large number of neighbor cells competing for the same channel, which is an issue when they all try to transmit at the same time (as in SFN) but still need to apply LBT. These challenges make it non-trivial to enable SFNs on unlicensed spectrum. While some countries the regulation does not enforce listen before talk, it would be challenging to enable large scale deployments that would not follow such an operational paradigm.

The rest of the paper is structured as follows: Section II provides an overview of the system model used, Section III discusses the key challenges for indoor VR broadcast. Section IV presents the simulation assumptions and system level parameters used for simulations, together with performance results of the proposed scheme. Section V gives summary of the paper.

II. System Model

In this work, we consider a system operating using unlicensed frequency bands, constrained by listen-before-talk - with each base station listening for channel occupancy before transmitting data and occupying the channel, similar to the one considered in [18]. The channel access mechanism used by two 5G base stations (gNBs) is as shown in Fig. 1. Due to the limited transmit power of such a system, we consider small cell network deployments, with the user equipment (UE) connected to the network for its communication needs. It is assumed that all the UEs request common data which is then delivered by the network using over-the-air broadcast.

For the sake of simplicity, we assume the LTE-A eMBMS network architecture shown in Fig. 2 for delivering the broadcast traffic, with enhancements to enable SFNs using unlicensed bands. The enhancements are mainly proposed on the synchronization protocol (SYNC) [19], which limits the impact on the radio access and core network entities. Here the multi-cell coordination entity (MCE) which configures and coordinates the radio transmission parameters within the RAN would also require enhancements, especially for the case when the channel is occupied by other transmitters. While the mechanisms described in this work are mainly from LTE-A eMBMS perspective, the solution is applicable to any multicast / broadcast capable network, which supports a central network entity for providing the timing for synchronized over-the-air transmissions.

III. Unlicensed Multicast / Broadcast

In this work, we consider the setup SFN transmissions with the help of SYNC protocol [19] enhancements in the Broadcast Multicast Service Center (BMSC), which translates the incoming data packets into SYNC protocol data unit (PDUs). The timestamp information in the SYNC PDUs enable all the BSs which are part of the SFN area to schedule the

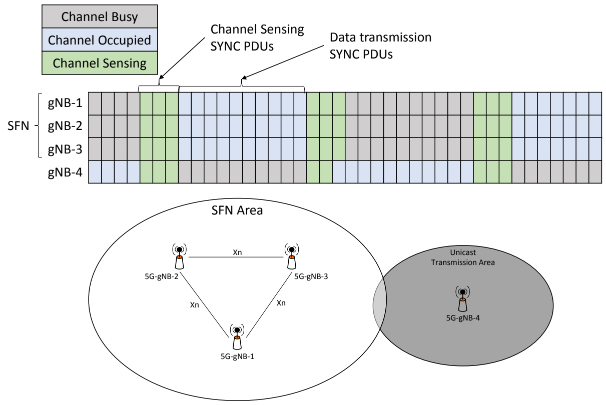

Fig. 4. Overview of the network for unlicensed Xcasting with complete interference coupling.

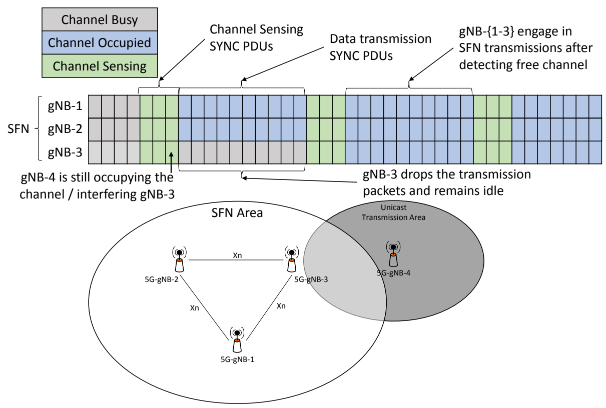

Fig. 5. Unlicensed Xcast network operation with partial interference.

multicast / broadcast transmissions in a synchronized manner. The enhancements enables the BMSC to inform the base station (BS) about the transmit time instances / subframes and the channel sensing time instances in a synchronized manner. The SYNC enhancements enables the network deployed on an unlicensed band to comply with the regulatory restrictions imposed by listen-before-talk form of communication. The BS based on the information contained in the SYNC PDUs, could determine the occasions for synchronized channel sensing and data transmissions. During the channel sensing time instances, if the BS detects the channel to be busy, then it drops the SFN

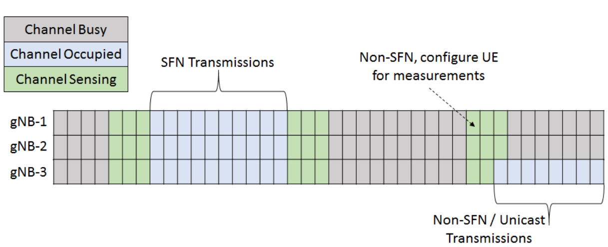

Fig. 6. Channel access for listen-before-talk with partial interference.

packets and remains idle during the data transmission time instances. In this work, LTE-A is used as a baseline since the current 5G architecture [20] has been designed only for unicast.

Various options for SYNC protocol enhancements are as shown in Fig. 3, based on the various PDU types currently defined [21]. Here we consider three possible alternatives – a) The usage of frame type-0 for channel sensing time instances or subframes and possibly for other types of transmissions (occupied / busy), b) Use the spare bits within the different frame types to indicate the action to be taken during each subframe or time instances, c) Use the null payload within frame type-1 and 2 for configuring the channel sensing time instances. The use of SYNC enables the distributed deployment of BSs within the network and avoids the need for low-latency interfaces in order to coordinate the BS transmissions.

The operation of the proposed mechanism is as shown in Fig. 4, with 5G-gNBs-$(1-3)$ forming an SFN area, whereas 5G-gNB-4 operates independently having its own set of unicast transmissions. The 5G-gNB-4 is assumed to have significant interference coupling with 5G-gNBs-$(1-3)$, thereby limiting SFN transmissions on time instances when 5G-gNB-4 occupies the unlicensed band. Here the key idea is that the gNBs-$(1-3)$ would be coordinating its transmissions and channel sensing opportunities, while ignoring possible busy indications from gNBs which are part of the SFN area, since that would be the desired mode of operation. The information related to coordinating gNBs / base stations could be provided by the BMSC using the SYNC PDUs with the MCE making appropriate configurations in the RAN, for setting up the SFN service flow sessions. The coordination information could be related to the absolute time instances where such transmissions are expected to be sent, based on the timestamps in the SYNC PDU. Here the information could also include the subframes / radio frames where such transmissions are expected after sensing the channel to be free and acquiring the channel. The key scenario considered here is that the gNB-4 is essentially interfering with all the SFN gNBs - (1-3). When there is no interference from the neighboring access points (which are not part of the SFN), the MCE configures regular radio transmission parameters in order to ensure coverage and capacity within the SFN area.

The system behavior for the partial interference coupling case is as shown in Fig. 5. Here the unicast gNB-4 has interference coupling only with gNB-3, which is part of the SFN network together with 5G-gNBs-$(1-2)$. Here the behavior would be that gNB-3 would simply drop the packets meant for transmission, upon sensing that the channel is busy for time instances or subframes where the SYNC PDUs are meant to be transmitted. The gNB-3 would also signal to the MCE (potentially using the interface M2-application protocol (AP) enhancements) about the inactivity during the upcoming data-transmit time instance. MCE upon receiving this message would adapt the radio transmission parameters of the remaining active base stations for the current transmission time instance, in order to ensure coverage and capacity, with possible spectrum scaling. Normal procedure resumes during subsequent time instances, when the gNBs within the SFN area engage in channel sensing based on the configurations from the BMSC and start transmitting after receiving such configurations in a synchronized manner. Here, if all the base stations detect the channel to be busy, the data transmit PDUs are buffered until the next transmission instance. Another boundary condition for this action could be if the number of base stations unable to transmit are above a certain threshold, then the base stations could skip the current transmission instance and buffer the data until the next transmission instance. It is assumed that proper cell planning and appropriate isolation in the data transmission areas could prevent such an event from occurring. The network could also have a rough coverage map(s) for different base stations, based on which it can determine if the blocking is affecting the coverage substantially or not. Condition could then be whether there are areas where the combination of transmitting base stations is not providing sufficient coverage.

UE measurements are an integral part of such technology enablers for 5G. From an UE perspective, the gNBs should configure the UEs to report interference / reference signaling received power (RSRP) measurement reports from only those gNBs / access points (APs) that are not part of the SFN transmissions. This could essentially mean that if the UE measures another gNB / cell whose ID is not part of a configured list, and the measured energy/power levels are above a threshold, the UEs would send measurement reports accordingly. Thus, the coordinating gNBs / base stations part of the SFN service flow session should configure UEs with new RRC measurement configuration to send measurement reports only when transmissions are detected from gNBs / base stations / access points which are not part of the SFN service flow session. With the help of explicit gNB / base stations cell / beam IDs along with the signal strength configurations for measurement reporting, the UEs can optimize the amount of feedback that is required to be sent without additional explicit configurations. Here the UEs would also be configured to conduct measurements only during those time instances where SFN service flow transmissions are expected. This would enable true-XCast scenarios where the gNBs could switch seamlessly between uni-, multi- or broad-cast.

Such a scenario where the gNBs engage in non-SFN transmissions at particular time instances are as shown in Fig. 6. The coordination between gNBs for channel sensing, including possible exchange of such measurement information between gNBs using new information elements defined over the Xn interface. Since beam-based system is one of the key design elements of 5G, the mechanism could also be applied on such scenarios, where the coordination needs to be done at a beam-level rather than the cell level.

IV. Simulation Results

A. Simulation Assumptions

One of the key questions about the mechanisms is its effectiveness, considering the fact that some neighboring access points operating in the unlicensed frequency bands can cause interference and essentially block the channel. We provide initial performance results in terms of the impact on user throughput while operating an SFN in unlicensed spectrum. We consider a small cell network that is assumed to operate in 60 GHz unlicensed frequency band, with 1 GHz of system bandwidth. An SFN area consisting of up to 5 BSs deployed in an indoor 80 m x 60 m area is considered where, 0-2 BSs are inactive due to LBT requirements due to an interfering BS in proximity. The system level parameters used for simulation are as shown in Table I, based on the values and assumptions used in [11]. The base stations and UEs are assumed to be dropped randomly within the simulated indoor area, with UEs receiving broadcast traffic from the active BSs within the SFN area. The UEs are assumed to remain static during each simulation drop and a new location assigned during the next drop, with sufficiently large number of drops used to obtained sufficiently randomized results.

The signal-to-interference-noise ratio (SINR) and throughput values are shown for individual users, with the multicast / broadcast network assumed to be optimized for the radio conditions of the worst user. Here the worst user is considered, as compared to 95th percentile value used for wide-area multicast / broadcast networks, due to the provisioning of high-

TABLE I
System Level Simulation Parameters

Basic Radio Configuration Parameters	
Small Cell Deployment	Random, $N_{SC} = 5$
Shadowing Standard Deviation	Small Cell: 3 dB
Carrier Frequency	60 GHz
Small Cell Max Tx Power [dBm]	30
Antenna Gain [dB]	Small Cell / 5
UE Tx Power [dBm]	21
Other Simulation Parameters	
Spectral Efficiency, S_{eff}	4.0
No. of RBs, N_{RB}	5000
PRB size, RB_{s}	180 kHz
Bandwidth Efficiency, B_{eff}	0.65
SINR Efficiency, $SINR_{\text{eff}}$	0.95
User Placement	Random, $N_{UE} = 600$
Traffic	Full Buffer

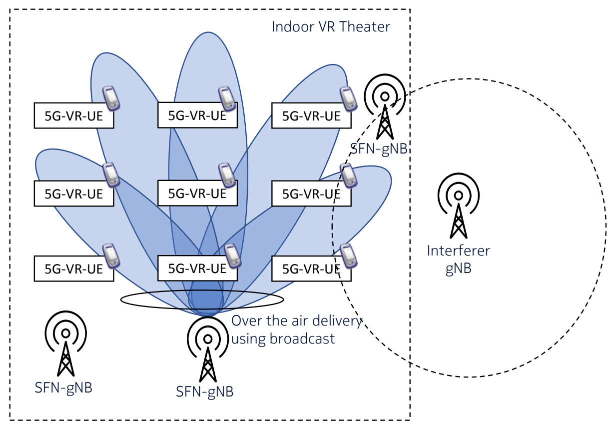

Fig. 7. Scenario used for simulations.

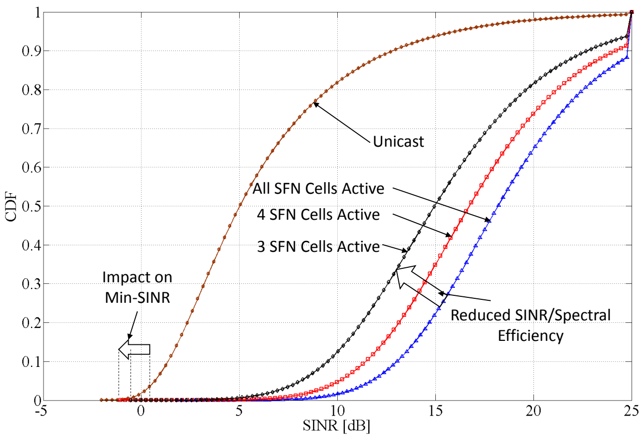

Fig. 8. User SINR distribution.

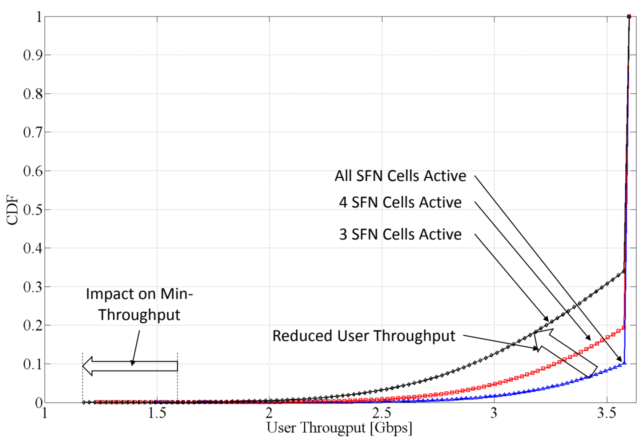

Fig. 9. User throughput distribution.

quality immersive content which requires better coverage with lower latencies. We assume that all the UEs have line-of-sight link with all the BSs, and due to the low-cost assumptions of the μO networks, the 5G base stations are assumed to use omni-directional antennas for broadcast. The throughput calculations are done based on the modified Shannon formula proposed in [22], with multicast / broadcast specific parameters considered in [2].

B. Simulation Results and Analysis

The SINR distribution for UEs with different levels of BS activity is as shown in Fig. 8, for the partial interference coupling scenario. From the figure, we can observe that as the activity level of the BSs are reduced, possibly due to an interfering BS / AP in proximity, the SINR experienced by the users also deteriorate. This is due to the additional interference generated by the interferer AP occupying the channel and the reduced received signal strength from the remaining active BSs. But the performance of SFN with limited BS activity factor is still significantly better than with the usage of unicast, for delivering common content to the end users as shown in the figure. This is similar to the performance evaluations

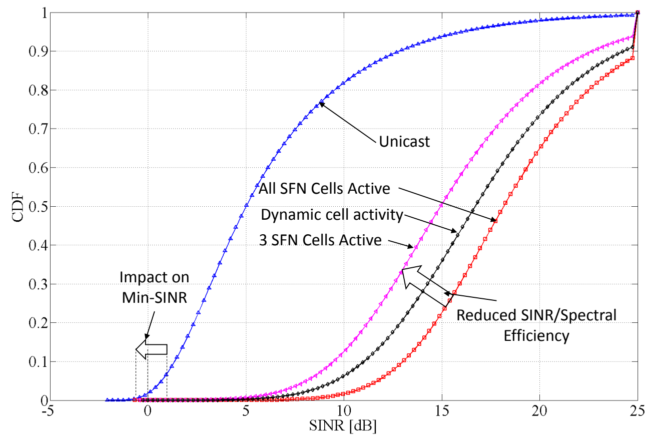

Fig. 10. User SINR distribution with dynamic activity factor.

presented in [11]. The impact of the inactive BSs on the overall user throughput is as shown in Fig. 9. From the figure, we can observe that even when a significant number of the BSs are blocked from occupying the channel, the impact on end user throughput (especially cell-edge or min-throughput) is minimized due to the formation of SFNs, with minimal interference for the data transmissions.

The SINR distribution with an SFN with dynamic network activity factor - where a dynamic number of base stations between 3-5 are active due to channel occupancy by a neighboring access point, is as shown in Fig. 10. Here, the SINR distribution for unicast, 3 and 5 active cell cases are provided for comparison. From the figure, we can observe that the performance of the network with a dynamic activity factor provides similar results as the scenario with 4 SFN cells active, shown in Fig. 8 due to the average of the results.

Based on the performance evaluations presented in this section, the significant gains from having SFN areas within indoor coverage areas is shown. The SFN could be setup using the proposed SYNC protocol enhancements in a distributed manner, with limited impacts on the operation of the 5G-gNBs and on the interfaces between them. Such enhancements enable localized deployments of new and immersive media services using 5G small cell networks, while limiting deployment costs using unlicensed bands. Due to the availability of significant contiguous bands in unlicensed millimeter wave spectrum, such solutions would also enable gigabit data rates with significantly lower latency.

V. Conclusion

In this work, we consider the usage of unlicensed spectrum for PTM transmissions with the setup of spectrally-efficient SFNs using SYNC protocol enhancements. Based on the performance evaluations, it is shown that such enhancements can provide significant performance gains with the ability to setup SFNs while conforming to LBT requirements. Detailed evaluations of the proposed enhancement, considering realistic network deployment challenges including interference-limited networks, have indicated significant potential both in terms of throughput enhancements and interference reduction. The distributed solution imposes limited implementation complexity on the network and latency requirements on the interfaces between the base stations.

The future work in this area will evaluate the possible optimizations of the radio parameters used for the SFNs in order to maximize the performance of such deployments especially with dynamic and low base station activity factors. The impact of delay, due to longer inactivity in full interference coupling scenarios, on end-to-end content delivery would be an interesting area of further study. The use of caching to mitigate delay and uplink feedback to improve reliability would also require further evaluations. The implications of 5G centralized RAN (C-RAN) architecture on the SYNC protocol and the enhancements required for unlicensed band operation using SFN also requires further study.

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