A Study on Data Dissemination Techniques in Heterogeneous Cellular Networks

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Abstract. Cellular networks are undergoing a major shift in their deployment and optimization. Regardless the deployment of LTE led to an overall performance increase in cellular networks, disseminating data to multiple users inside a cell is still under development. This dissemination is currently achieved via unicast connections, which is inefficient in terms of throughput and power consumption because the antenna is sending duplicated data to co-located users. The 3rd Generation Partnership Project (3GPP) proposed a new standard to be able to multicast and broadcast information over cellular networks. However, different studies stated that this solution might have problems related to the spectrum, and new multicasting alternatives which provide better performance have appeared. Since these new alternatives came up, a race for the control of cellular multicast/broadcast has started. In this paper, we collect, analyze and compare the leading technologies that enable the system to efficiently disseminate data over cellular networks, and conclude by indicating which ones are the most likely to succeed.

Keywords: Survey · Cellular networks
Random Linear Network Coding (RLNC) · Multicast
Cooperative networks · 5G · Traffic offload

1 Introduction

Over the last years, the amount of traffic over cellular networks has greatly increased year by year. In the Technical Report of Cisco 2011 [1] it was reported that the global Mobile Traffic was going to increase from 1 exabyte (eB) per month to more than 10, and the traffic of mobile video will reach the 70% of this traffic. Credit Suisse reported that 23% of base stations globally had utilization rates of more than 80 to 85% in busy hours during the deployment of LTE [2]. In the end, 11 eB was reached in 2017, and the trend is to continue growing up to 49 eB in 2021 [3], where 78% of the traffic will be video streaming. The amount of wireless traffic will increase as well, comprising a 63% of total IP

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traffic by 2021. Moreover, the number of devices will massively increase up to three times the global population in 2021. New infrastructure elements, such as femto/pico base stations, fixed/mobile relays, cognitive radios, and distributed antennae are being massively deployed, thus making future 5G cellular systems and networks more heterogeneous [4]. With all these information above exposed it can be concluded that, during the next years, the actual infrastructure and protocols will not be able to support the amount of traffic between devices due to mobile video.

Nowadays, each user requesting data from a broadband connection will be connected to a unicast link from the cellular base station to the user equipment. In the case these users are requesting the same video file, a replicated scenario appears for each of user who is downloading the same data. Hence, an efficient way of disseminating data over cellular networks must be developed. Several lines of research have appeared with different principles and different results. Even though all these novel technologies have appeared, there is still no study that compares all of them and gives an idea of where each technology could stand out.

The aim of this paper is to gather the current leading technologies that enable multicast/broadcast over cellular networks, analyze and provide a holistic comprehensive comparison of them in terms of throughput, latency, energy consumption, packet resilience, protocols used and assumptions made. We discuss which problems have been tackled, which challenges are still on the plate and what are the potential research directions in the field. We also summarize which ones would stand out in a near future and which impact they will have in this field.

The remainder of the paper is organized as follows. In Sect. 2 we give a detailed information about the current leading technologies studied. In Sect. 3 the key enablers of these technologies can be found. Section 4 gathers the possible comparison approaches in disseminating data over cellular networks. In Sect. 5 a summary table with the main technologies named in the paper and its major properties is depicted. Section 6 collects the correlation between the studied publications, differences, and similarities. In Sect. 7 the conclusion of our work is presented.

2 Data Dissemination in Cellular Networks

The simplest dissemination scenario studied in standards consists on a communication where one source is sending to multiple sinks simultaneously and only one single transmission is used. The first approach to provide data dissemination in cellular networks was done by the Conventional Multicast Scheme (CMS) [5] in 2000, which describes an optimal allocation algorithm for an OFDM broadband system in comparison with TDMA. An alternative approach is the Optimized Opportunistic Multicast Scheduling (OMS) [6], where not all User Equipments (UEs) are served in a given time slot but maximizes the system throughput according to the channel quality, as it is studied in [7]. In a similar line of research, the 3GPP group developed the Multimedia Broadcast/Multicast

Service (MBMS) [8], who transforms an LTE network into a single frequency network (SFN) from a device perspective, to enable broadcast or multicast of any type of content to interested users, such as live sports events, live concerts or a news service; and the enhanced version of it [9,10]. In this approach, a basic WiFi multicast scenario is replicated in the cellular network, with similar discovery, initiation, transfer, and termination protocols. The deployment of MBMS would have been unquestionable, however, diverse research studies [7,11,12] found some technical constraints that stalled its expansion, mainly in terms of spectrum.

Parallel studies [13,14] have developed new methods in order to provide an efficient data dissemination in mobile networks. The principles these methods use are based on the creation of small subgroups inside the cell. New applications [15–18] that use this approach have recently appeared. These small subgroups often behave as cloudlets [19] with intermediate nodes acting as relays in order to offload traffic from the cellular network. The work in [20] shows that relaying inside cells increases network performance. In these scenarios, the cellular base station has to make sure the information is sent at least once to the whole subgroup via unicast links, and then a short range (SR) communication protocol, e.g. WiFi, is used to distribute the data over the nodes inside the group. Since the speed of WiFi is higher and energy consumption is lower [21–23] than LTE, systems that use this architecture argument that by offloading the LTE traffic from cellular networks onto WiFi they will increase network throughput and devices battery lifetime.

The last approach to be studied in this survey is the content sharing in cellular networks through device-to-device (D2D) systems [24,25]. In this approach all nodes in the cellular network behave as if they were in a mesh network, being able to talk to their respective neighbors and share their information with their peers via unicast connections. It can be studied as a particular example of a subgrouping architecture where the cell behaves as the subgroup and nodes cannot multicast among themselves.

3 Background

Broadband Communication in Heterogeneous Networks. Cellular networks are undergoing through massive changes in the last years. New elements have recently appeared making the environment heterogeneous [26,27]. The size of cells is diminishing year by year. Currently, femtocells are the type of cell which is most likely to succeed in small cell networking [28]. These cells are small, which is important because it may allow a short-range communication between the nodes in the cell using different communication protocols with lower ranges.

Cooperative Mobile Wireless Systems. Nowadays, in the cellular environment, a massive amount of users are coexisting in a cellular network, and the trend is to continue increasing [3]. In the case those devices are downloading the same content and they are close enough to communicate among themselves, gathering nodes in groups may reduce the overall data to be transmitted over the cellular network [29–31] as well as the energy consumption per UE. Thus, the base station will be able to offer a better Quality of Service to the user or to have access to a bigger number of nodes. This cooperative architecture is known as mobile Clouds (MC) or Cooperative Mobile Clouds (CMC) in [32–34]. A mobile cloud is a cooperative architecture that shares distributed resources in efficient and novel ways [35].

Traffic Offload from Cellular to Short Range Networks. The amount of traffic in cellular networks will increase 700% in the next five years [3]. This increase in the amount of traffic is unaffordable for the current cellular architectures, therefore several solutions such as offloading traffic [18,36] from the cellular network to short-range networks have appeared. In [37,38], opportunistic device-to-device communication, and cellular communication are used to disseminate the content taking into account social ties and geographical proximity.

Raptor Codes. Rapid Tornado Codes [39] are a class of erasure correction codes that improve the first practical approach of fountain codes, called LT codes [40]. They were first introduced in 2004, but the first dedicated publication was [41]. It was very successful in its early stages, where the 3rd Generation Partnership Project (3GPP) [42] defined the Raptor Codes as the main codes to be used in mobile cellular wireless, defined in IETF RFC 5053 [43]. These codes were also used for future 3GPP protocols in cellular wireless communications for multicasting, as in [8].

Random Linear Network Coding. In this emerging heterogeneous networking environment where cellular networks are continuously adapting to new user requirements, it was demonstrated that the use of Network Coding can increase wireless network throughput [44]. A high-performance improvement used to overcome those errors is Random Linear Network Coding (RLNC), which was first introduced in [45]. Some studies also stated that the interplay of Random Linear Network Coding along with different technologies (such as Cooperative Networking [46,47] or other correction techniques [17]) can substantially increase network throughput and packet resilience in comparison with its predecessors and have created an innovative communication paradigm known as Network-Coded Cooperative (NCC) networks [48,49]. This tool has been as well a great way of designing broadcast/multicast applications [50,51]. Since users will be close to each other, middle nodes in cooperative clouds can work as relays and take advantage of the interplay between RLNC and cooperation [52].

4 Classification Schemes

There are two well-differentiated lines of research in this field. On one hand, some researches are trying to adapt the multicast technology of WiFi to broadband communications. On the other hand, researches opt for the creation of small subgroups inside the cell, unicasting information to the group only once, and then spread the data inside the subgroups. Figure 1 shows the two possible approaches. In the first one, there is a single frequency communication from the base station where each UE is able to subscribe to. In the subgroup-based scheme part, the content is delivered to each UE that requests it via a unicast connection, and each node of the subgroup shares its data to the rest via P2P or Wifi multicast. The impact of different error correction techniques, the amount of throughput or latency in the output, the power consumed in each device or in the base station, the different communication protocols used, are some of the features that will be important for this survey.

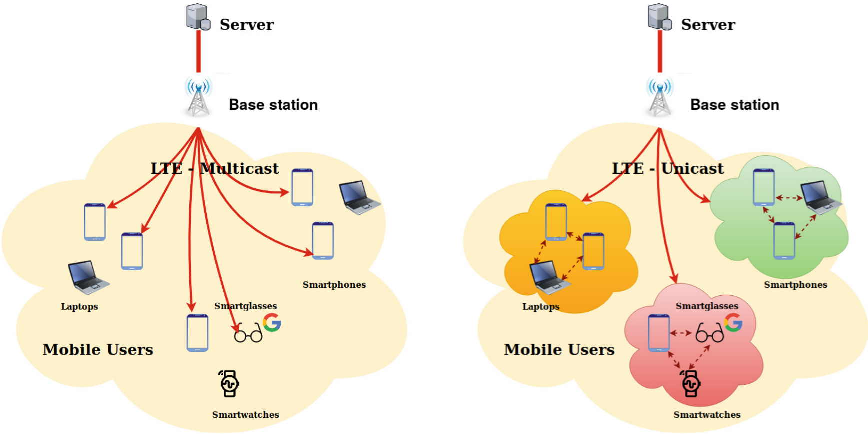

Fig. 1. Conventional Multicast Scheme (Left) versus Subgroup-based Scheme (Right).

5 System Comparison

In Table 1 the main technologies to multicast data in cellular networks are gathered. Some are enablers to other models, they have different approaches, or their assumptions are different, but all of them have the same objective, the possibility to multicast over cells.

eMBMS is the most robust one since it has been developed by the 3GPP group. It was the first one developed, taking the model of IP multicast and [5,6]. However, EBU technical Report [11] showed that multicasting over 3G and later over LTE had several technical issues that needed to be improved before deploying eMBMS to the world. Multiple use cases in different platforms were studied and the main drawbacks found were:

- Signal attenuation, requirement of LoS (Line of Sight)
- Location of the UE and the nodeB
- Eco-system development
- Spectral inefficiency
- Disagreements with LTE network operators

Table 1. Comparison of current leading technologies. 1. Model presented. 2. Nature of the model. 3. Cellular communication notes. 4. Short Range communication notes. 5. Error correction techniques. 6. Results obtained. 7. Asumptions made for the protocol.

Arch.[1]	Approach[2]	Cell.[3]	SR Comm.[4]	Error Corr.[5]	Results[6]	Asumptions[7]
CMS [5]	Analytical	OFDM	-	-	Capacity Increase	Quasi-static channel, Full information of channel
OMS [6]	Analytical	TDMA	-	Raptor codes	Minimum Delay	Channel SNR known
eMBMS [9]	Holistic	LTE	-	Raptor codes	3GPP Framework	-
NCVCS [15]	SR Tool	None	WiFi Mcast	Network Coding	Reliability in lossy channels	-
Microcast [16]	Application	LTE	Wifi Ucast	Network Coding	New model	UE: 2 Ifaces
AL-RLNC [17]	Application	LTE	Wifi Ucast	RLNC + HARQ	Higher Through-put	Small testbed
CoopStream [18]	Application	LTE	Wifi Ucast	RLNC	Cell Offload	UE: 2 Ifaces
NCC Netw. [49]	Application	LTE	Wifi Mcast	RLNC	Energy Gain	UE: 2 Ifaces
Coop. D2D [25]	Application	LTE	Various	-	Cell Offload	No error communi-cation

Since eMBMS is the technology to beat, most of the alternatives presented are using these drawbacks to state that their solutions can compete with eMBMS. However, most of the studies focus only on one specific part of the development process (Analysis, Application) or the testbeds they are doing are too small. These subgroup-based schemes are right now taking the lead in the main mobile conferences and multiple institutions are researching on it. In Table 1, it can be observed these new approaches, using similar technologies and, in the end, obtaining different results depending on what they are focusing on. It would be easy for somebody who values throughput over latency to select [17] instead of [16]. The main problem these approaches have is that UEs are required to have 2 interfaces. However, it is expected that next generation phones can use both LTE and Wifi interfaces at the same time to download data.

Another topic discussed in this paper is about the short-range communication protocol used in the subgroup-based scheme technologies. Some of them consider Bluetooth, but it is rapidly discarded due to its short range. WiFi is the selected technology. However, there is still not clear if WiFi unicast should be used or if WiFi multicast is better. Unicast provides better reliability, but wifi multicast spreads out the data in a more efficient way since it is designed for that. Further researches should be done on this aspect. Regarding the error correction techniques, RLNC is taking the lead over other NC codes or raptor codes. RLNC is performing better and it is the most likely to succeed in the near future.

6 Publication Correlations

Since there are different approaches to solve the same problem, correlations between the publications are also separated into two groups. On one hand, the eMBMS group, which comprises CMS, OMS, and eMBMS. On the other, the sub-grouping scheme group, formed by NCVCS, Microcast, NCC Networks and D2D Cooperative Networks. The technology to beat is eMBMS since it is the one proposed by the 3GPP Partnership Project. That is the reason why all the subgrouping publications work around eMBMS and its troubles encountered to multicast, so they give another possible solution with better performance.

Another form of grouping can be the differentiation between the enablers [5,6,15], and the applications [9,16,25,49]. [5] and [6] are two ground technologies looking for the same purpose, adapt the unicast to OFDM/TDMA in order to be able to multicast. This is the starting point of eMBMS, however, different studies [7,11,12] showed that this technology had complications. Hence, novel approaches appeared, such as [16] or [49], who had [15] as an enabler, or [25] using a different approach.

7 Conclusion

Cellular networks are undergoing a major shift in their deployment and optimization. Even though the deployment of LTE led to an overall performance increase in cellular networks, disseminating data to multiple users inside a cell is still under development. The Third Generation Partnership (3GPP) proposed a solution, eMBMS, to deal with the increasing amount of traffic. However, it was reported that this solution had troubles in several aspects which stalled this technology from its deployment. Hence, alternative approaches appeared based on a subgrouping scheme where the cellular base station send data to some nodes in the cell, which will work as relays. The new approaches proposed got better results in terms of throughput, latency and power consumption. However, these technologies have not been tested in real scenarios, and further researches must be carried out following this line of research.

There are several problems that need to be overcome in both approaches (IP multicast adaptation and subgrouping schemes) in order to deploy LTE multicast in the near future. On one hand, the 3GPP group needs to find the optimal solutions to the problems explained in this paper. On the other hand, the subgrouping scheme technologies should move their testbeds to a bigger scale, within a whole cell in a real heterogeneous environment. Moreover, most of them are developing applications, but equations supporting the results and models of the protocols are missing.

Even though eMBMS looks like the strongest technology nowadays, alternative technologies are obtaining better results in terms of throughput, latency, and energy consumption, and the spectrum issues of eMBMS do not seem to disappear. Hence, we rely on the subgroup-based technologies to take the lead and end up being the multicast alternative for 5G.

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