Uplink Traffic in Future Mobile Networks: Pulling the Alarm

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Abstract. Mobile wireless networks are designed and dimensioned according to mobile users downlink traffic. Downlink has been dominating wireless traffic since early 3G systems. Nowadays, we are witnessing a massive integration of novel applications and services into wireless networks, mostly through cloud architecture and technologies. The accessibility of cloud services from mobile devices increases demand over uplink traffic, which increase in uplink traffic enlarges the uplink to downlink ratio. Are current wireless networks capable of serving the increasing uplink traffic? Are DL-based network dimensioning and mechanisms adapted for such a change in traffic patterns? We launch a call for a future challenge to overcome in wireless networks: the uplink. In this paper, we set the issue of an inevitable uplink traffic explosion in future mobile networks. We discuss contributing factors in uplink traffic changes, as well as some research solutions for increasing networks uplink capacity.

Keywords: Uplink traffic · Cloud · Future networks · Mobile networks

1 Introduction

Cellular networks have always been designed, dimensioned, and deployed based on the downlink (DL) mobile users' demand and traffic patterns. The reason for leveraging downlink traffic was the asymmetry — then true — between uplink (UL) and DL traffic. In other terms, the capacity required in the downlink was much higher than the one required in the uplink. Therefore, designing networks with higher data rates to offer in downlink than in uplink was trivial. More precisely, within early 2G based cellular networks, the traffic load for both UL and DL have been roughly the same. This has also been the case for the very early 3G systems. It is not until the 3.5G and 4G systems that downlink traffic load greatly surpassed uplink requirements [1]. In these systems, with the eruption of IP based networks and high speed access to the Internet through cellular networks, traffic is dominated by downlink. The data explosion in downlink and uplink was asymmetrical. While downlink traffic grew exponentially, uplink traffic was also subject to an increase, however, the traffic demands in both directions were not equal. Mobile users downloaded more than they uploaded. The estimated

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ratio of uploaded to downloaded data is about 1:7 [2]. Thus, current mobile networks are dimensioned based on the amount of data mobile users are downloading according to downlink traffic models. As the fastest growing segment of the communication industry, wireless communication, and especially cellular systems, have experienced, and are still experiencing, exponential growth over the last decade. Many new applications, services, and technologies have and will integrate the wireless network. The way mobile users see, use, and exploit mobile networks have changed. Mobile networks are nowadays the provider of unlimited number of heterogeneous services that differ in data requirements. As some are mainly downlink based, others have equal requirements of uplink and downlink traffic, or depend on large amount of data upload, like cloud storage for example. Today, the asymmetry between UL and DL is reduced, and sometimes inverted. These changes evoke a set of questions: What is the impact of network evolution on uplink traffic? Have networks started experiencing uplink traffic explosion? Should networks continue to be designed, planned and dimensioned according to downlink traffic only? What has been done to increase uplink network capacities? These questions are of great importance, especially under the fact that very low attention has been given to UL traffic models comparing to DL. Indeed, uplink traffic lacks of tractable models since it depends on users actions and unplanned interventions that are often less easily accessible and predictable. In contrast to downlink traffic that has been given significant attention, attempts to model the uplink have been limited [3]. With an increasing number of connected devices and mobile subscribers, the integration of cloud enabled technologies in wireless networks, the convergence of IoT systems, the development of M2M and MTC platforms, and many other factors, it is important to understand if and how new communication networks will cope with challenging uplink traffic loads. The idea is not about uplink rising over downlink traffic. We do not assume or consider that uplink traffic overtakes the downlink — although this might be the case in specific scenarios. We only present the uplink as a new important player that should be considered when setting network design and dimensions. Even though there are no precise forecasts on uplink, the traffic pattern change is inevitable. A study by NSN in 2013 showed that the overall UL to DL usage ratio reaches approximatively 1:2.4 [4]. In addition, the Ericsson mobility report of 2012 shows that UL to DL ratio reaches 1:1 for bi-directional applications such as P2P TV, email, and P2P sharing [5]. With the availability of high data rate services, new applications are enabled, and mobile devices energy consumption increases. Cloud technologies, sensor networks, device to device communications and social networking are all growing trends that increase uplink traffic and do not rely solely on downlink traffic. All of these trends introduce applications where mobile users create content and launch actions on the network, which changes the classic UL-based traffic pattern adopted in wireless networks. The research community, aware of the upcoming uplink traffic volume change, is already proposing some solutions in the network for improving uplink capacity.

In the remainder of this paper, we present the major factors that contribute to the uplink traffic explosion in the current/future mobile networks. Then we discuss some of the efforts that have already started by the wireless community to improve current networks uplink capacity in order to cope with mobile users' increasing uplink demand.

2 Contributing Factors in Uplink Data Traffic Increase

2.1 Increase in Number of Mobile Subscribers and Devices

The number of mobile subscriptions and mobile devices has been constantly growing since the first deployments of cellular mobile networks. From 6.4 billion mobile subscriptions in 2012 to 7.2 billion in early 2015, the ever-increasing index is to reach 9.2 billion by 2020 according to latest mobility reports [6]. Mobile broadband that was accounted for 2.9 billion out of the 7.1 billion subscriptions will grow its share to occupy 7.7 billion out of the 9.2 billion subscriptions in 2020, which is around 85 % of all subscriptions. As the number of fixed broadband and the number of related devices such as mobile PCs and mobile routers will have very low growth, and the number of total mobile subscribers and subscriptions will increase linearly, the number of mobile subscriptions will increase exponentially. Smartphones, which already are the main mobile equipment (2.6 out of 2.9 billion), are expected to double in number by 2020. Mobile broadband will be accessible to everyone and mobile devices will continue to outnumber the earth population. By 2020, mobile phones will be in possession of 90 % of humans over 6 years old. The growth of mobile devices and users showed in numbers gives an idea of how data traffic (in both uplink and downlink) could increase.

2.2 Evolution of Cellular Networks

Since wireless Internet, wireless generations adopting new technologies for increasing system capacity have been designed and deployed. The increasing users' traffic demand required a network evolution to cope with constant changes. However, for all consecutive technologies and wireless generations, downlink data rate far exceeded uplink. Due to possible technical challenge and asymmetry in traffic demand, mobile networks were always dimensioned to assure higher DL capacity. Table 1 shows the difference in up and downstream data rates among technologies. Note that the table shows advertised peak data rates, which are usually higher than nominal achieved rates. Evolution of wireless networks and users' traffic demand are in perpetual evolution and growth, one implying the other. Indeed, wireless network evolves to *"give more"* for mobile users and cope with their increasing traffic. At the same time, when offered more capacity, mobile users would like to *"do more"* with their mobile equipment through the wireless network. Numbers show that the proliferation of new wireless generations offering higher service quality attracts mobile users. Since the introduction of HSPA and then LTE, the number of mobile users continues to grow strongly. In the third quarter of 2012 HSPA and LTE subscriptions increased by 13 and

65 million respectively. As for GSM/EDGE it attracted then 20 million new subscriptions. With LTE proliferation in the market, the numbers in the first quarter of 2015 are as follows: 105 million additions for LTE, 60 million for HSPA, and a decline of 30 million for GSM/EDGE. These numbers and Fig. 1 show how the market follows the offer of new technologies and increasing service quality. LTE will have, alone, 3.7 billion subscriptions by 2020. In conclusion, the number of mobile users and the evolution of cellular networks are joint in an escalating increase relationship; where the increase of the first requires improvement in cellular networks, which re-attracts more mobile users to subscribe.

Table 1. Cloud architecture evolutions comparison

Technology	Generation	Downstream (Mbits/sec)	Upstream (Mbits/sec)
EDGE	2.5G	1.6	0.5
EVDO (Rev A)	3G	2.45–3.1	0.15–1.8
HSPA	3G	0.384–14.4	0.384–5.76
HSPA+	3.5G	21–678	5.8–168
LTE	4G	100–300	50–75
LTE-A	4G	1000	500

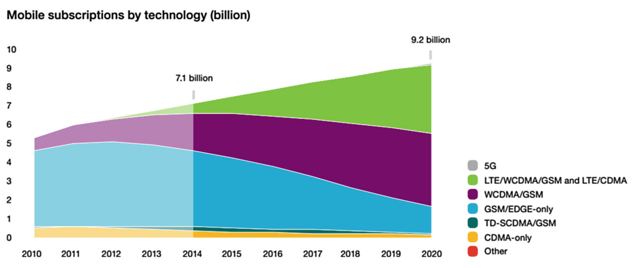


Fig. 1. Mobile subscriptions by technology [6]

2.3 Emergence of Cloud Technologies and Dense Heterogeneous Networks

Cloud technologies are progressively but rapidly integrating wireless networks. Cloud radio access network, remote cloud computing, cloudlets, and mobile edge cloud, are all new technologies and architectures in which the cloud concept integrated wireless networks. Cloud technologies in mobile networks consist on delegating computing, storage, data processing, and other resources consuming functionalities to a computing entity instead of performing the tasks on the mobile devices. Cloud in wireless networks can take different forms. It can be a centralized remote server pool, a nearby cloudlet, or an edge computing platform. Aside from cloud computing, cloud can be used as a remote storage location. As mobile equipments in general suffer from lack of resources of computing and storage, mobile users are more and more relying on outsourcing required storage and computation capacities. With cloud storage, mobile users can take photos or record videos with their mobile devices and directly upload them for saving on the cloud instead of their devices. In such applications, uplink is as important as downlink and thus should be taken into account in network dimensioning.

Another emerging deployment technology in wireless networks is Heterogeneous networks (HetNets). All mobile users are not served by the same type of base stations. Along with classic large coverage macro-cells, cellular networks are being intensively deployed with pico-cells, relays, and femtocells. One of the main motivations and interests of heterogeneous networks is offloading heavily loaded macro-cells. Users in reach of a femtocell, for example, will communicate with the latter instead of a congested macro-cell. As femtocells are deployed at closer distances from mobile users, communication channels between femtocells and mobile users are very often characterized by a better signal to noise ratio. Due to the lack of tractable models, the impact of such offloading on the uplink performance is not well understood [3].

Uplink traffic modeling has not gained the same attention as downlink. Both directions differ fundamentally in access modes, heterogeneity of transmitters, and resources management. The invasion of wireless networks by cloud enabled heterogeneous network certainly has an effect on traffic patterns especially in uplink, since new offloading opportunities are available to consumers. With the adoption of offloading computation and the concept of virtual machines (VM) and enable applications such as videoconferencing in enterprises and improved network mobility support, upload speeds become critical against users' experience quality and content efficient delivery to the cloud. With the development of cloud technologies, upload speed and capacity will continue to have an important impact.

2.4 New Applications and Services Ecosystem

Cloud based wireless networks are the next breakout of the wireless communication. Cloud is integrating many functionalities of the wireless networks and increasing their capabilities. Whether a remote cloud or an edge cloud, the cloud unlocks a whole new ecosystem of services and applications. Application developers have now the door open to new types of applications that can be run on the cloud and that were not adapted before to the mobile concept due to heavy resources requirements. Furthermore, cloud and services providers work on increasing their infrastructure ability and performance through improving availability and reliability: An evolving ecosystem that will push forward the cloud based offer and demand, and thus create higher cloud related traffic requirements. Among the applications that are now compatible with the mobile network, we distinguish different types of traffic requirements. Some applications require very high downlink and/or uplink traffic with varying latency constraints. Applications that comply with downlink based networks include streaming basic video and music and web browsing, where upload requirements are relatively low. Streaming relies basically on high downlink traffic, as for web browsing it has in general lower traffic requirements. However, numerous applications do not comply with that model. Many applications require roughly the same amount of upload and download such as web conferencing (cloud-based), video conferencing, tele-medicine, virtual office and connected vehicles safety applications [7]. Others, on the contrary, require more traffic upload than download such as web electronic health records, virus scanning, face recognition, cloud storage, and aggregated data analysis. Hence, the heterogeneity in new services and applications has non-negligible impact on traffic patterns and on the importance of uplink. The diversity of services offered through the Internet requires a management of network capacities in order to avoid both functional and economical harm to wireless communication infrastructure and businesses and their customers.

2.5 Crowded Networks Scenarios

Mobile networks are designed based on peak network traffic and the ability to serve in peak hours. This has led into excessive energy consumption. Several solutions were proposed for this problem such as base station sleeping. Furthermore heterogeneous networks deployment helps by offloading traffic from congested macro-cells onto smaller base stations. Now that solutions exist, the network should be dimensioned to keep its efficiency in peak data traffic scenarios. Peak traffic does not only concern downlink, uplink traffic is also subject to peak demands. Crowded scenarios are the best example for such situations. We take the example of a football stadium were thousands of people are gathered to watch a game. In such situations, mobile users share their experience through social networks, texting or talking. They post photos and videos during matches. A study by Ericsson [6] about the FIFA 2014 football games showed that social networking and texting were used during the matches and traffic peaked at half time. Ensuring a good user experience in such scenarios is a challenge to operators. Network planning and optimization are necessary. What is important to notice in crowded scenarios is the footprint of uplink traffic. According to the same study, the ratio of uplink in total data traffic was as high as 50 % during the final game of the world cup. The normal ratio in the same location is between 12 and 17 %. The increase in uplink traffic is clearly non negligible and should be taken into account during network planning and dimensioning. The study showed that 61 % posted or sent pictures via the Internet, and only 25 % used the Internet to find and download content related to the world cup. The numbers also showed that more users posted videos (33 %) than watched videos (18 %) through the Internet. Video uploading data usage is quite high especially that smartphones and tablets camera technology is quite advanced and 4 K video enabled. Furthermore, in many sports events, uplink traffic surpasses downlink in some time windows. With the accessibility of high data rate services such as 3G and 4G, mobile users will be more active uploading data and using social networking. 4G users, which have higher data rates, are more active than 3G users. This proves what was stated in Sect. 2.2 that users with higher services will want to do more. Even though 30 % of data traffic was handled by 4G networks, 4G users consumed 70 % more data than 3G users.

2.6 Sensor and MTC Networks

The evolution of sensor networks and Machine Type Communications (MTC) has been more than evident in the last decade. Mobile devices, sensors, and all types of objects already or soon will be equipped with sensors and RF circuits in order to integrate the wireless communication network. The Internet of Things is a well-known application of such networks that is creating a new trend and imposing a breakthrough in network management. In most wireless sensor networks scenarios, data is aggregated from end equipment (sensors) into a gateway that communicates with the network infrastructure. As for machine to machine (M2M) communications that allow devices of the same type to intercommunicate is also requiring an increasing role in the wireless network. Any device to device (D2D) communications can be established through different scenarios, where control link can be managed by end devices or the network. In D2D communications, especially scenarios where control is done by the network, uplink traffic is at least equal to downlink. Figure 2 shows a simplified level architecture of how the M2M system will be connected to wireless networks. The capillary network, which represents the set of communicating machines, aggregates data in a M2M gateway that is connected to the network and may use cellular communication. The convergence of sensor networks and cellular has been studied in literature. The European FP7 SENSEI project [8] focuses on the integration of WSN (Wireless Sensor Networks) and actuator networks. With the expected

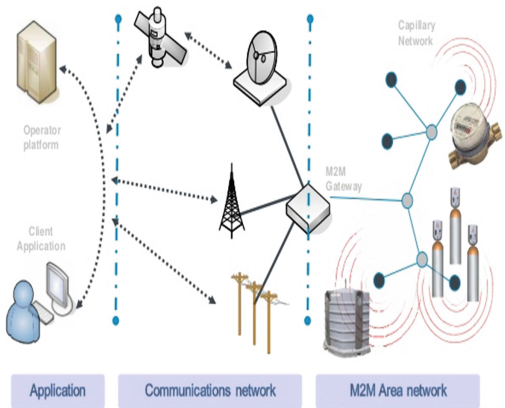


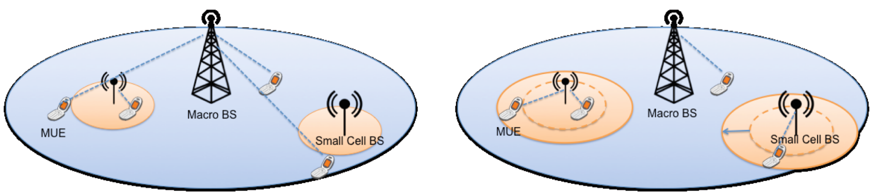
Fig. 2. High level simplified M2M architecture

increasing deployment of IoT devices and services, the traffic generated by these devices may change current traffic patterns. In fact, regarding the number of connected IoT devices, an estimated 50 billion "things" will be connected to the Internet by 2020 according to Cisco [9]. As for traffic patterns, current traffic models do not take into account traffic generated by smart devices. And since mobile networks are designed according to those patterns, they may not be adapted to such applications that are mostly uplink traffic generating. It is then necessary to understand how smart devices will affect network traffic and include it in network optimization and dimensioning.

3 Uplink Improvement Related Work

3.1 Range Extension in Heterogeneous Networks

Coverage Range Extension (CRE) in heterogeneous networks is a technique that can help increasing the uplink/downlink fairness. In an area covered by both macro-cell and a small-cell, the MUE/ Base Station (BS) association is based on the downlink received signal power only. And since small cells are characterized by a smaller transmit power than macro-cells, and are randomly deployed, they are expected to have large areas with low signal to interference (SIR) conditions [10]. In the uplink, the strength of the signal does not depend on the BS transmit power. It depends on the mobile device transmit power and the received signal power at base stations depends on the channel gain. This results in boundaries mismatch between uplink and downlink handover in heterogeneous networks. And since small cell coverage ranges are smaller than those of macro-cells, we notice unfair distributions of data rates between macro and small cells due to different loadings of connected users. The proposed solution is to balance the load between macro and small base stations by expanding the range of small cells (see Fig. 3). This is achieved by associating users to base stations based on path loss instead of received signal power. This will be in favor of uplink network performance since minimum path loss association maximizes uplink coverage rate [3]. Nevertheless, range expansion lead to high interference levels in the downlink which imposes using interference coordination techniques.



(a) Base stations coverage limits without CRE

(b) Base stations coverage limits with CRE

Fig. 3. Cell Range Expansion (CRE) impact of base stations footprint

3.2 Downlink and Uplink Decoupling

From the first generation to 4G, downlink and uplink of cellular networks have been coupled. Indeed, mobile users' equipments have been connected with the same base station in both uplink and downlink directions. As mentioned earlier, the best base station and user equipment couple is not necessarily the same for both directions. While for uplink it is best to connect UEs with the base station with the highest received signal power, for downlink, the best association is the one that minimizes path loss. Adopting a downlink centric association negatively affects load balancing in heterogeneous networks as well as uplink overall performance. Nevertheless, adopting an uplink centric association through cell range expansion creates interference problems for uplink users. As a solution, uplink and downlink association decoupling has been proposed in order to optimize communications in both directions [1,11]. Association decoupling is expected to increase uplink SNR and reduce transmit power, improve uplink interference conditions, improve uplink data rate, allow distribution of users among macro and small cells, and achieve more efficient resources utilization and uplink rates. This technique indeed proved to achieve up to 200 % improvement in the 5^{th} percentile uplink throughput in a simulation based on a live Vodafone LTE test network deployment in London [11]. Nonetheless, the concept of uplink and downlink decoupling is considered as one of the components of future cellular networks [12,13]. However, this technique requires changes in system design since it needs mechanisms to allow acknowledgment process between serving base stations for uplink and downlink, strong synchronization, and data connectivity between base stations.

3.3 Uplink CoMP Techniques

Uplink Coordinated Multi Point (CoMP) is a new technology introduced with the LTE systems, which consists on jointly processing signals that are received at different antennas and/or base stations. It is the uplink analogy of CoMP where a single user is served by more than one base station (see Fig. 4). In uplink CoMP, users' signals are captured by more than a base station and processed jointly. Uplink CoMP can be deployed through three different scenarios: Intra-cell CoMP, Inter-cell CoMP, and between macro and small cells in heterogeneous networks. Inter-site CoMP is easily deployed since all signals information are inside one cell. Intra-site and heterogeneous CoMP require however low delay high capacity backhaul support between base stations. We note that uplink CoMP is transparent to mobile users in the sense that mobile equipment do not need to be aware of the base stations receiving their signal. Therefore, uplink CoMP does not change the association complexity on the mobile equipment side. By jointly processing received signals at different base stations, uplink CoMP results in uplink improvement. Uplink CoMP achieves uplink gain from both macro diversity reception and from enabling uplink/downlink decoupling in heterogeneous networks. Uplink perceived capacity is improved in high interference and poor coverage conditions. Important gains can be achieved especially in locations where uplink and downlink optimal associations are not the same, i.e. in locations where the most powerful received signals and the minimum channel path loss are not of the same base station. In a full scale field trial in LTE network [14] uplink CoMP proved to achieve 3 Mbps improvement in uplink throughput, and 100 % throughput gain if coupled with downlink/uplink decoupling.

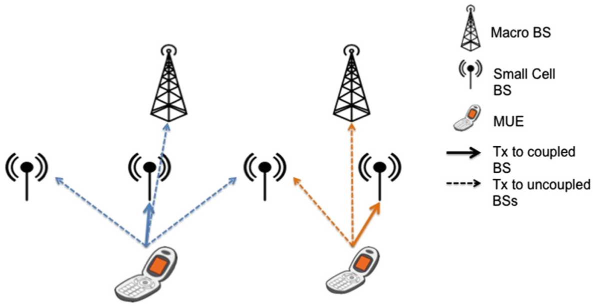


Fig. 4. Uplink CoMP usecase example

4 Conclusion

In this paper, we set the challenge facing uplink communication in future wireless networks. We focused on the upcoming increase in uplink traffic demand. We discussed several factors that contribute in validating changes in traffic uplink bottleneck and help prove that the upcoming uplink traffic explosion is a fact. Inscriptions number increase, wireless networks evolution, emerging cloud technologies, cloud enabled ecosystem, and convergence of sensor and actuators networks are among the factors with influence on uplink traffic. We then discussed some research work and studies that are proposed by the communication society that can help improve uplink network resources management, and increase uplink capacity in current and future networks. However, there is still no clear uplink traffic patterns that can validate if the existing efforts are enough for coping with the upcoming challenge. Until the emergence of a clear vision of how future networks will encompass uplink traffic explosion, we keep the alarm on.

References

1. Boccardi, F., Andrews, J.G., Elshaer, H., Dohler, M., Parkvall, S., Popovski, P., Singh, S.: Why to Decouple the Uplink and Downlink in Cellular Networks and How To Do It. CoRR, abs/1503.06746 (2015)
2. Electronic Communications Committee (ECC) CEPT, Asymmetry of Mobile Backhaul Networks (2012). http://www.cept.org/documents/se-19/6560/se19

3. Singh, S., Zhang, X., Andrews, J.G.: Uplink rate distribution in heterogeneous cellular networks with power control and load balancing. In: 2015 IEEE International Conference on Communication Workshop (ICCW), pp. 1275–1280, June 2015
4. Nokia Solutions and Networks, Nokia Solutions and Networks TD-LTE Frame Configuration Primer, November 2013
5. Ericsson, Ericsson Mobility Report, On the Pulse of the Networked Society, November 2012. http://www.ericsson.com/res/docs/2012/ericsson-mobility-report-november-2012.pdf
6. Ericsson, Ericsson Mobility Report, on the Pulse of the Networked Society, June 2015. http://www.ericsson.com/res/docs/2015/ericsson-mobility-report-june-2015.pdf
7. Cisco, Cisco Global Cloud Index: Forecast and Methodology, 2013–2018 (2014). http://www.digital4.biz/upload/images/10_2013/131028130134.pdf
8. SENSEI, SENSEI EU project (2010). www.sensei-project.eu
9. Cisco, Fog Computing and the Internet of Things: Extened the Cloud to Where the Things Are (2015). https://www.cisco.com/web/solutions/trends/iot/docs/computing-overview.pdf
10. Qualcomm, LTE Advanced: Heterogeneous Networks, January 2011. https://www.qualcomm.com/media/documents/files/lte-heterogeneous-networks.pdf
11. Elshaer, H., Boccardi, F., Dohler, M., Irmer, R.: Downlink and uplink decoupling: a disruptive architectural design for 5G networks. In: 2014 IEEE Global Communications Conference (GLOBECOM), pp. 1798–1803, December 2014
12. Andrews, J.G.: Seven ways that hetnets are a cellular paradigm shift. IEEE Commun. Mag. **51**(3), 136–144 (2013)
13. Boccardi, F., Heath, R.W., Lozano, A., Marzetta, T.L., Popovski, P.: Five disruptive technology directions for 5G. IEEE Commun. Mag. **52**(2), 74–80 (2014)
14. Li, L., Butovitsch, P.: Uplink CoMP, the applications in LTE heterogeneous networks: principles and the field trial. In: 2013 15th IEEE International Conference on Communication Technology (ICCT), pp. 309–314, November 2013