Next Generation ITS Implementation Aspects in 5G Wireless Communication Network

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***Abstract*—In the paper the study of Intelligent Transportation systems implementation in the 5G wireless communication network is presented. Firstly, small-cell concept in Ultra Dense Heterogeneous network was analyzed. Secondly, the 5G network requirements were presented which are important from the point of view of transportation systems development. Next, the study on the 5G network architectures proposals dedicated to the ITS systems and some examples of ITS implementation were analyzed. An original ITS wireless system architecture using Body Area Network sensors for rescue operation is proposed. The goal of the paper is presentation of major perspectives for global ITS development in the 5G networks.**

Keywords—ITS; 5G, WBAN, 5G network architecture, V2V, frequency reuse

I. Introduction

The development of Intelligent Transportation Networks needs to use efficient radio access networks to send large amount of data. Especially, it's well known that dominant type of communications in next generation radio communication network will be so-called machine-type communications, independently on user-type communications. We can see that a major difference between machine-type and user-type communication is that user-type transmission is typically non-constant in time. User-type transmission can be continuous if e.g. large amount of data is downloaded but typically it needs user interaction and sending some commands. Additionally we have large breaks in transmission time.

On the other hand, in the case of machine-type communications transmission is rather more continuous and connections are established for a very long time. Thus, we can see that reliability of transmission is critical. Nowadays, when we use some sensor networks rather relatively small amount of data is transmitted. But we know that in next generation networks the amount of data can be much greater and more resources will be used to transmission, especially if e.g. high bit rate connections from sensors are established or multimedia communication (e.g. camera as sensor) is realized. Thus realization of some multimedia-based services needs much greater amounts of data.

The sense of next generation radio communication networks, called 5G, is to achieve global access to wireless transmission with large transmission rates, high rate stability and reliability as well as low latency to support real time transmissions. It should be taken into account that the 5G networks can offer and support evolutionary growth of current services and additionally support new services which can introduce new critical requirements. Thus, we have to expect the evolution of available radio access technologies and completely new technologies for wireless transmission.

The major challenge is implementation of new model of the 5G access network architecture in which small-cell concept is proposed. In this case the network will be implemented as heterogeneous network (HetNet) with hierarchical cell structure of high density of small cells located at areas of large cells, called macro-cells. This type of HetNet is called Ultra-Dense Network. Global radio access in new 5G network needs work due to problems of its reliability, stability of transmission rate at overall cell area, signalization traffic, resource management and advanced interference coordination, handover providing for high mobility etc.

II. Network Architecture Challanges

A. *Small Cells Concept*

The 5G network will be implemented as global heterogeneous Ultra-Dense Network (UDN) in which hierarchical cell structure will be dominant. In this type of network, large-cells, called macro-cells will cover large areas of a network. Additionally, small-cells will cover small areas inside macro-cells. These small-cells are of different type what we can

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see in Fig. 1. In the UDNs advanced methods of resource management and very large number of small cells located with high density will be used. Within the group of small cells we can use micro-cells, pico-cells and femto-cells dependent on their application. In the concept of small-cells, the use of these cells can be important from the point of view of general network performance because we can improve the cell throughput and latency of signals transmission. Additionally, it allows greater resource distribution over entire area of network and their virtualization [1]. It means that division of cells onto small cells guarantees short cell ranges and less power of signals transmitted and, as the result, less power of inter-cell interference (ICI). Small ICI power guarantees higher stability of transmission rates on overall cell area, in particular at a cell edge, and greater spectral efficiency and cell capacity.

The major difference between homogeneous and heterogeneous networks is larger number of cell types. First step for implementation of UDNs is introduction in LTE-Advanced (as 4G system) virtual cells, using the concept of small-cells. In this case we have the separation of control-plane and user-plane [2]. So, the control-plane is managed by macro-cell eNodeB with high power and large range but transmission of physical, useful signals of users or machines is realized in small-cells only (so-called user-plane) at short distances and using signals of low power. In small-cells available resources are in part virtual and these cells are called phantom-cells. Phantom-cells can be virtual (all resources or some parts of resources). We can see that in this case control-plane is then separated from user-plane and the use of resources is more distributed comparted to typical cellular systems

It means that the transmission of user data relates, in general, only a small area of cells. While control data transmission is realized by macro-cell eNodeB and allows realization of connections by UEs connected directly to macro-cell and connected to phantom cells. In eNodeB also the physical resource management can be implemented for direct management of macro-cell resource allocation and phantom-cells located on the area of this macro-cell. Macro-cell eNodeBs also cover the areas of small phantom cells.

It gives more efficient the resource use in a network, more efficient frequency reuse and much greater transmission rates in small cells compared to macro-cells with centralized resource use models [3]. Very important is additionally the reduction of inter-cell interference levels for better quality of transmitted signals, support the process of handover in closely spaced, small cells [2] as well as reduction of signaling traffic.

Thus, the major difference between the 5G and the 3G/4G networks is more efficient distribution of network elements as well as physical resources and change of centralized resource utilization models to distributed models. First step for this was the change of 4G network architecture compared to 3G, in which abandoned the use of radio network controllers (RNCs), for direct communication of eNodeBs with core network devices. But the second step is the implementation of heterogeneous small-cell concept using phantom-cells in 4G LTE-Advanced.

There is no doubt that in the 5G networks the concept of small-cells and phantom-cells is one of the major directions of network development. Thus Ultra-Dense Networks will be the major type of the 5G network architecture. Additionally, we can say that concept of phantom-cells is a first step to implementation of the 5G networks in which the virtualization of radio resources is one of major challenges.

Of course the implementation of global UDNs is great challenge from the point of view of network management and resource utilization procedures both frequency reuse methods and data scheduling. But it opens the new era for development of machine-type transmission networks, especially Intelligent Transportation Systems.

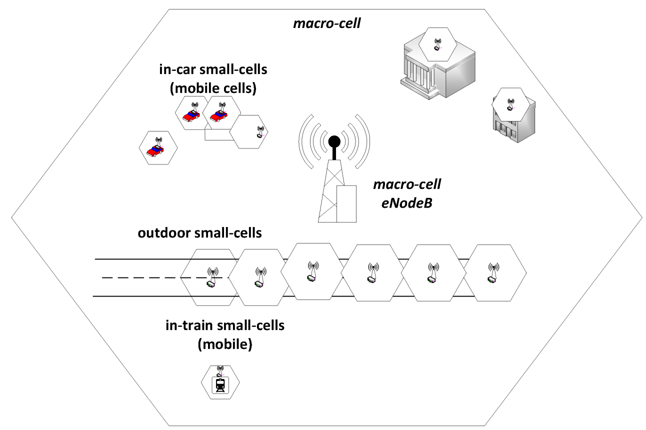

Fig. 1. The concept of small-cells network.

The ITS is typically defined as the set of applications to provide innovative services for transport of various modes and allow transport management and coordination as well as traffic safety improvement. The ITS is not a communication network but it is a set of applications implemented in this network. These applications are strictly related to machine-type communications network and Internet of Things. Thus, the novel model of the 5G radio communication network architecture is of great importance for ITS implementation and other types of systems in which the communication between devices is necessary.

All projections indicate that in the coming years the communication between machines, called Machine-to-Machine (M2M) communications (and related techniques) will become dominant in 4G and the 5G radio access networks [1, 3]. The traffic generated in wireless communications networks by different machines, devices and others, becomes larger than the traffic generated by humans. In telematics it means a revolution in the availability of new services, in the scope of systems work and technical capabilities for the development of various sensor and communication infrastructure.

III. THE 5G NETWORK REQUIRMENTS

Requirements for the 5G network are defined by ITU [1] and we know that independently on new network characteristics the evolution of 4G network will be continued. Thus, we can find major requirements for next generation network architecture, service quality and other aspects, which can be grouped as follows:

- Network architecture requirements related to new network functions and services development.
- Transmission quality aspects and available throughput in relation to global radio access.
- Service-type requirements i.e. connection-type and communication-type evolution and growth aspects.

A. Architecture Requirements

Requirements set to the 5G network architecture result from new models of cell structures and from the concept of total change in cellular network towards UDN development. We can find major requirements which are as follows:

- Global UDN development, especially in cities including small-cells concept and phantom-cells.
- Ubiquitous, continuous things communication.
- Scalable and flexible infrastructure and network architecture.
- Distributed network devices and distributed radio access to physical radio resources.
- Cloud communication and virtualization of resources in distributed architecture.
- Centralized RAN (Radio Access Network) and distributed radio units, e.g. access points, radio resource elements, relays etc. which are managed by eNodeB and connected to it by e.g. optical link.
- Massive MIMO communication devices development.
- Advanced resource management in distributed heterogeneous network.
- Implementation of virtual cells and realization of large number of services in internet cloud,
- Proposal that nodes or access points can realize only front-end (radio access) functions but the reception and decoding of signals can be done in centralized eNodeBs or some servers in a cloud.

B. Transmission Quality Requirements

Realization of high-rate connections between thousands of devices causes necessity of meet the requirements as follows:

- Very high transmission rate for connections and ubiquitous radio access of great stability of transmission rate at overall area of cells i.e. reduction the number of low-rate transmissions at cell edges.
- Very low latency for transmitted signals over entire network and in each cell.
- High connections and radio access reliability.
- Transmission parameters should be optimized for machine-type communications and user-type communications, and optimized for large number of users/machines of high density of their location.
- Greater role in network design and for quality evaluation the subjective users experience and satisfaction.
- Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication with satisfied quality, reliability and latency, optimized as additional class of services and their quality requirements.
- High mobility and speed of terminals should not decrease significantly quality of connections.

C. Service-Type Requirements for ITS

All of these requirements should include modern concept of service realization in a network as follows:

- The service of large number of users/machines including very high density of their location, which will be possible provided that a satisfactory transmission quality for end-users under specific conditions, e.g. during fairs, concerts, etc.
- Implementation of ITS services makes it necessary to take into account the specific conditions of their realization as M2M communications using different types of cells and radio interfaces as well as types of transport-oriented functions.
- The problem of high mobility of terminals in ITS applications and large speed of vehicles should be resolved due to problems of transmission rate and stability of connections and their reliability. It is very important for high speed cars at highways and expressways and for fast trains. The problem of high mobility was not resolved in 3G and 4G networks. In view of advanced applications of V2V (Vehicle-to-Vehicle) and V2I (Vehicle-to-Infrastructure) for real-time communication services reliability of connections is critical. The success of the concept of global communication between vehicles depends on high reliability of transmission with high quality and transmission rate at high speed of vehicles motion [4].

- Enhanced multimedia services requirements, including those related to medical assistance, safety and security in ITS. Important group of these services is related to development of WBAN (Wireless Body Area Networks) which can be applied to ITS for improvement of road safety [4, 5].
- Requirements of location-based services of high accuracy. These types of services are necessary for precise localization and navigation of vehicles: cars and, in this, autonomous cars, trains, but additionally drones and other unmanned vehicles, etc.
- The problem of an unprecedented increase in the number of devices for ITS and other systems related to Internet of Things growth in wireless networks. It can be large problem with stability of connections when there is a need of continuous connection and continuously sending the data to other machines and people with different and varying requirements for energy consumption, power of signals transmitted and introduced delays et al.
- General concept of service virtualization causes many research problems resolving due to transmission in Internet cloud.
- Requirements for autonomous vehicles (without drivers) control and communication as well as other unmanned vehicles communication and control are the challenge for new era in communications what is not only technical problem but e.g. law problems.

IV. Proposals of ITS Network Architecture

A. General ITS Architecture

General concept of ITWS implementation is based on the 5G radio communication network architecture. In Fig. 2 we can see an example architecture of some components of global ITS.

In general, we can see that the concept of small cells is introduced and in each model of dedicated ITS we use macro-cells and a number of small-cells. Macro-cells cover a number of small cells. Access points of small-cells can transmit and receive signals from mobile stations. Additionally, we can see that small cells can be of different type. Firstly, we have classic cells of fixed location at area of a city, along roads, in buildings etc. But we can find some new class of cells which are mobile-cells. These mobile cells are located in-trains, in-buses, in-cars or in trucks.

Communication between eNodeBs and access points as well as communication to core network can be done using fixed links based on optical transmission or sometimes based on fixed radio-links. Communication in macro-cells typically is based on the 5G radio access technologies or the 4G radio access based on OFDMA/SC-FDMA technology. Radio access technologies for small-cells can be different dependent on functions of cells. There is possible the use of existing access technologies as WiFi, or based on cellular systems as e.g. LTE. Additionally, there is proposed new radio access technology based on mmWave communication [1, 3] or others.

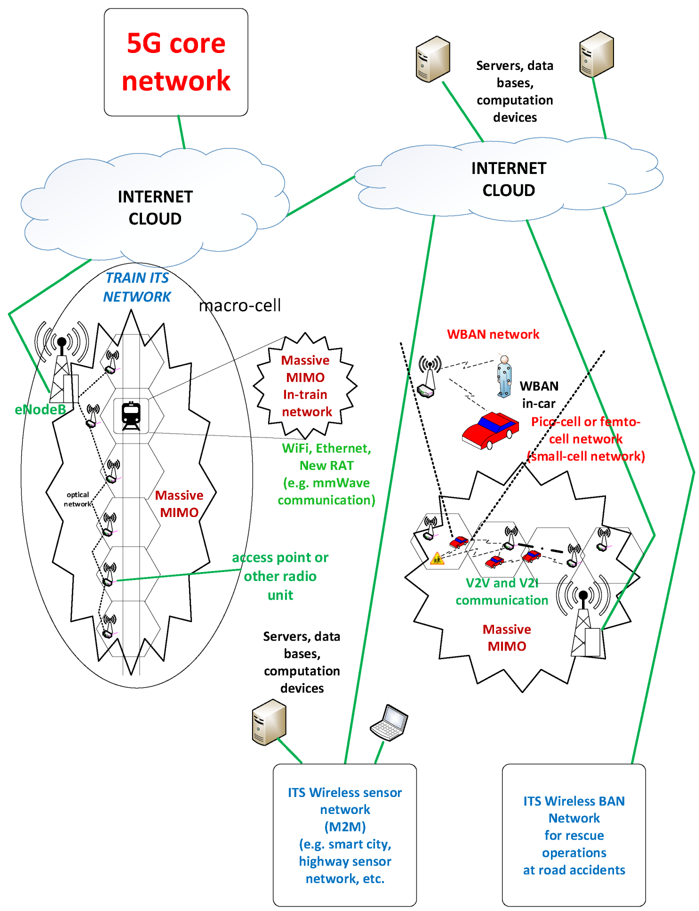

Fig. 2. General architecture of ITS system implemented in the 5G network.

Note, that small cells can be placed along the streets, highways or railway tracks. In the case of streets rather very small cells will be introduced but in the case of faster roads rather micro-cells should be used.

In presented figure a few types of ITSs were included which are as follows:

- V2V based ITS network with Wireless BAN (Body Area Network) in-cars.
- Train ITS network.
- ITS wireless M2M sensor network.
- ITS wireless BANs for rescue operations.

B. V2V based ITS and WBAN In-Car

V2V communication can be significantly supported by radio access network. In Fig. 2 we can see that there are possible communications V2V and V2I to infrastructure of a road. Global access to wireless networks allows the use of advanced protocols for preventing collisions and accidents, as well as for steering the traffic, remote control of a vehicle, autonomous car traffic of better security and integration of V2V system with smart city or other sensor ITS networks. It's obvious that the evolution in cars allows the development of completely new systems for transport applications, and it can be a revolution in road transport. But for efficient realization of these services is necessary to provide global and reliable access to radio communication networks with low latency and real time transmission. We know that for V2V communication can be defined new radio access technologies but it is absolutely essential the use of radio access standardized for global communication in the 5G.

The implementation of global V2X (Vehicle-to-Everything) networks [4] is true challenge for next generation systems. In these networks automatic collection of data can be made using real-time connections and real-time analysis. Data are collected from various sensors located in vehicles and on roads. The sensors can be of different type for monitoring of vehicles but additionally for monitoring of drivers health using additional medical devices.

The real-time exchange of information between the vehicles will be a breakthrough in terms of road safety. Moreover, the use of additional WBAN (Wireless Body Area Networks) for drivers [4], especially in large vehicles, will enable continuous monitoring parameters of their health. Decisions which can be the result of this monitoring and analysis can be completely crucial for the road and rail safety.

C. Train ITS for Passangers

We know that there is a great problem with global access to internet for passengers. So, for the 5G there is defined novel model of cellular communication which is very interesting from the point of view of train ITS. In present cellular networks, mobile stations, regardless of whether they are inside or outside buildings or vehicles, must communicate directly with eNodeB. For indoor users, walls are extra obstacles for signals and we have great additional signal loss which causes data rate decreasing and degradation of spectral efficiency. In 5G networks there are proposed the separation of transmission mechanisms inside and outside buildings and vehicles [1, 3] through the creation of local networks inside. As a result, additional walls attenuation will no longer have such a large impact on signal loss. It is possible the use of additional Radio Resource Equipment (RRE) and antennas located closer to mobile users and implementation of massive MIMO communication. Antennas can be connected by optical links but for indoor communication we can use WiFi or other techniques. Antennas located outside the train can resolve the problem with access to cellular network for passengers.

D. ITS Wireless M2M Sensor Network

This sensor network can be seen as a global M2M network e.g. for support transport in cities, along highways, express ways etc. Great performance of global 5G network allows the use of thousands sensors of different type for different services like traffic monitoring, other monitoring, rescue operations coordination, preventing terrorist attacks etc.

Internet cloud services can additionally define the rules for data processing and saving [6]. Typical city system uses own servers for saving and storage of data. In the 5G system data can be stored in Internet cloud what gives higher efficiency but there is necessary the change of users mentality and discourage fears of data loss or unauthorized access.

E. ITS Wireless BANs for Rescue Operation

ITS WBANs can be a new class of ITS systems for rescue operations, especially in situation of large road accidents (e.g. at highways) or terrorist attacks in cities. The model for WBAN implementation in ITS is presented in Fig. 3.

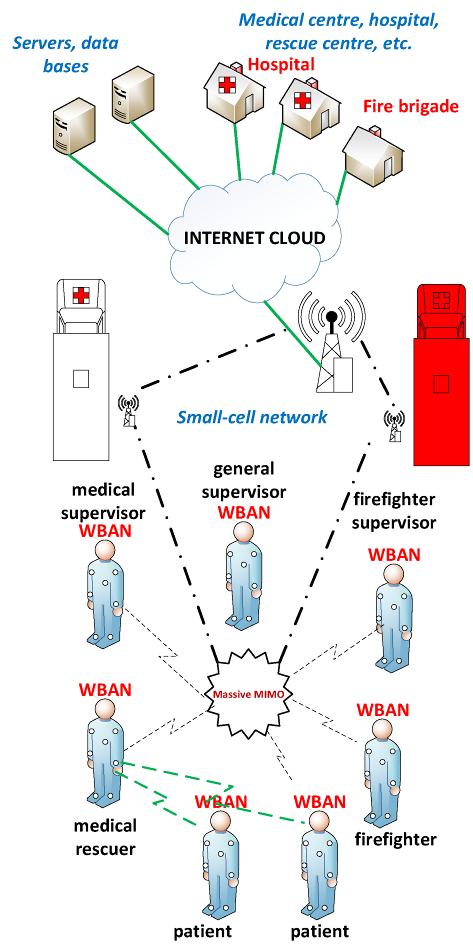

Fig. 3. ITS WBAN for rescue operation.

In this example the rescue operation can be conducted by teams of ambulances and firefighters. Medical rescuers, firefighters and selected patients who are the victims of accident are equipped by WBAN networks with their own sensors [7], performing different functions and connected to local ad-hoc network based on Massive-MIMO communication. WBANs of medical rescuers enable them to monitor the status of patient health and allow simple communication between themselves, supervisors and medical rescue centers. The WBANs of patients are in general for monitoring medical parameters of their organisms. The central point of communication can be located in an ambulance. Data from rescuers are sent to emergency centers, hospitals emergency departments, etc. It allows remote support of rescuers and notification of a hospital.

Functions of WBANs of firefighters are different. Sensors can be used for communication, location, monitoring the parameters of a body, and measuring environmental parameters surrounding a firefighter. Thus, these functions are related both to health and safety of firefighters but also to support his work, e.g. it can be used sensors for smoke, carbon monoxide, temperature, etc., and also the cameras transmitting images. The access point is located in a fire engine. There is possible the communication between firefighters and their supervisor as well as medical rescuers. But additionally data can be sent to emergency centers, department of fire brigade, a hospital etc.

F. Massive MIMO Implementation in ITS

Massive MIMO technique is based on the concept of implementation eNodeBs with large set of distributed antenna elements providing large spatial multiplexing gains and beamforming [6]. In this concept can be used tens or hundreds of distributed antennas for better transmission quality and spectral efficiency. The result of Massive-MIMO use is significantly higher data-rates to users distributed on area of cell. In ITS systems massive MIMO guarantees better throughput and capacity in cells and for each user/machine connected to the network. If advanced sensor network in ITS will be used then the implementation of Massive MIMO will be much easier compared to other systems. Thus this technique can be very important for M2M and V2V communication systems using heterogeneous network architecture.

V. RADIO RESOURCE MANAGEMENT AND COORDINATION

Advanced radio access network and advanced cell structures are the major part of the 5G network. New structures of cells in UDNs make it necessary to work on advanced mechanisms of radio resource management [6]. The result of this is the need for advanced coordination and management of radio resources, including different types of radio interface can be used in various types of cells. Used techniques can be based on advanced coordinated multipoint (CoMP) techniques and enhanced inter-cell interference coordination (eICIC). It is necessary to improve spectral efficiency in cells and in particular at cell edges [8]. A major problem is common using of frequency bands in a number of cells both macro-cells and small-cells. But this problem is different for these types of cells due to their various functions and different conditions of signals transmission. Proper management of frequency band e.g. when OFDMA technique is implemented (as in 4G LTE-Advanced) should be made in the way allows reduction of received power of inter-cell interferences [8].

It should be taken into account two types of interference coordination called resource scheduling and frequency reuse methods. Frequency reuse guarantees reduction of interference power at cell edges due to intelligent resource allocation in neighbor cells. There are a number of different techniques of frequency reuse [8] but most important are so-called Soft Frequency Reuse and Partial Frequency Reuse which are characterized in e.g. [9]. Very promising is modified technique called Soft-Partial Frequency Reuse which was presented in [10]. This technique connects advantages of both SFR and PFR and gives better performance and spectral efficiency at cell edge. Thus, it can be used as efficient component of the 5G network. But note that there is a need for research on frequency reuse when resource virtualization and phantom cells will be implemented. In general eICIC techniques have no specific requirements in terms of transport performance [6] but are very important from the point of view of general spectral efficiency, network capacity and quality of connections what have impact on ITS services reliability and quality.

VI. CONCLUSIONS

Next generation wireless communication network can change the world for global M2M communications network. As we can see in the paper, the 5G network will be optimized to ubiquitous machine-type communication. It opens new era in ITS development. One of major problems with slow pace of ITS development in Poland is difficult access to wireless systems of high reliability and expensive cost of communication. The 5G network which will be dedicated to M2M communications will be very good candidate for global development of transportation telematics systems. As proposed in the paper, architecture of the 5G is very advantageous for implementation of ITS services. Additionally, requirements proposed for the 5G are very promising from the point of view of ITS services implementation in global scale.

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