特集論文

スマート社会に向けた通信技術の役割

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The Key Role of Communication Technologies for Smart Society

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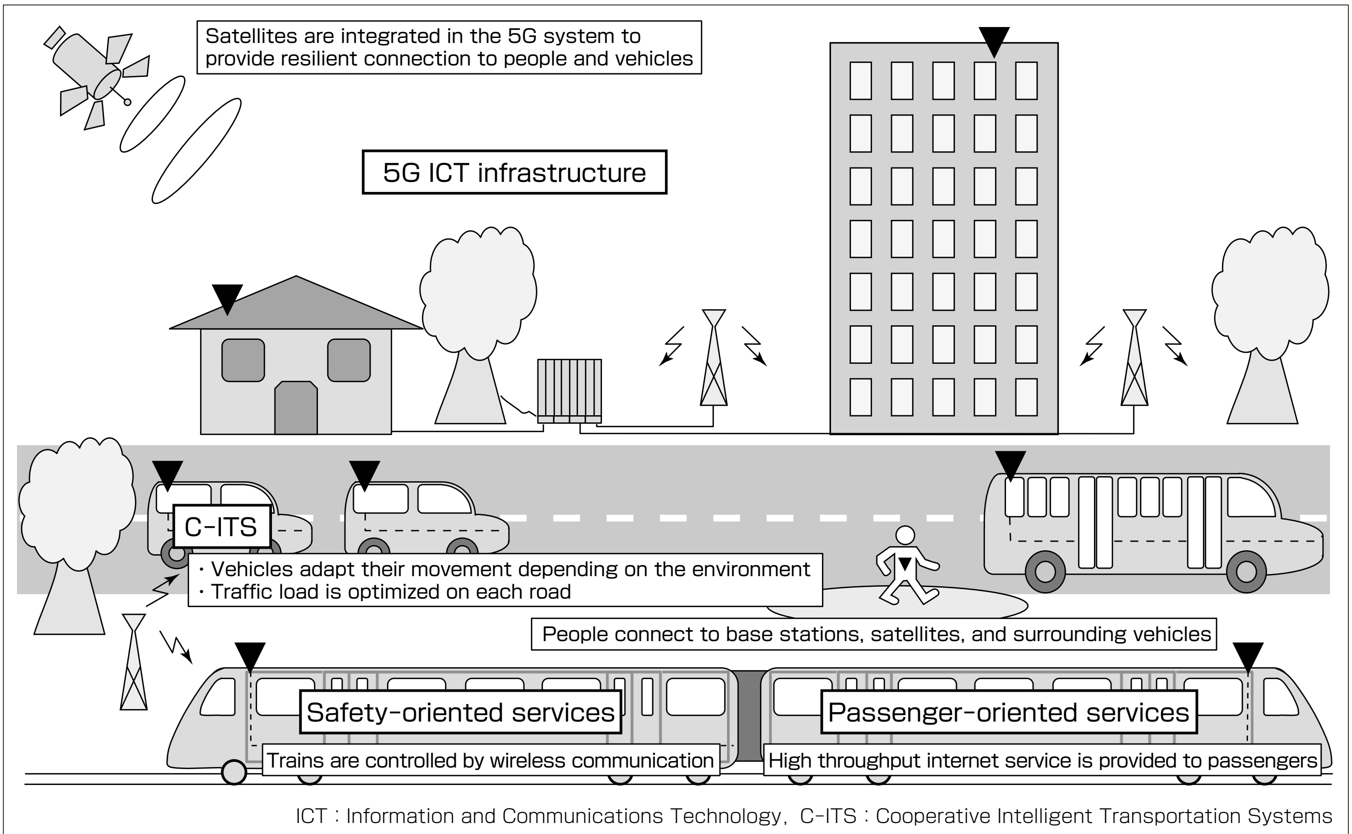
要　旨

都市部への人口集中が著しい欧州では，様々な課題が生じてきており，人々の生活の質を向上させるための，よりスマートな通信を実現する技術，及びサービスが必要とされている。欧州委員会は，列車や車等の交通システムへの通信技術の利用を進めることで，人々にとってより安全でより快適な社会の実現を目指している。

一方，交通システムでは通信技術を用いたサービスを提供する場合，その要求条件は，アプリケーションごとに異なっており，それらに柔軟に対応できる通信技術が必要である。さらに，現行の通信技術では性能が限られており，通信技術を活用した将来の交通システムに向け，更なる性能向上が必要である。特に，列車による高速移動環境下での通信性能の向上や，リアルタイムな通信の実現は，非常に重要な課題である。

また，5Gと呼ばれる次世代移動通信技術が世界各国で注目されているが，欧州では，携帯電話のみならず，交通システムのような事業者向けのシステムに対しても，非常に有望な技術として注目されている。特に，5Gではより高密度に基地局が配置されるようになり，それらの基地局がスマートに協調することで，ネットワークに負荷をかけることなくユーザーの高速移動にも対応可能である。



ICT：Information and Communications Technology，C-ITS：Cooperative Intelligent Transportation Systems

交通システムに通信技術を活用するスマート社会

列車や車等の交通システムへ通信技術を活用することで，人々にとってより安全でより快適な社会を実現するための，多様なサービスを提供していくことが可能となる。

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1. Smart Communities in Europe

Urbanization is a worldwide trend and a major evolution in Europe. Indeed, the average population density in Europe is in the order of 120 citizens per square kilometer, which is quite low but 75% of European citizens live in urban areas. By 2020, they will be around 80% in cities. In some countries, the ratio will reach 90%. This tendency, which has a direct impact on the quality of life of European citizens, strongly encourages the members of the European Union to take initiatives towards a smarter society.

In July 2012, the European Commission launched a strategic partnership between industry and European cities for smart communities, which integrates the Information and Communication Technologies'(ICT), Transport and Energy sectors(1). The major goal of this partnership is to realize tomorrow's urban systems and infrastructures by developing innovative solutions in order to solve the major environmental, societal and health challenges facing European cities today. Reducing traffic congestion, air pollution and energy costs are priority items.

Thus, this R&D initiative will define efficient urban mobility schemes, open data management, innovative business models and appropriate regulation to allow taking benefit from the needed integration of the communication, transport and energy networks. Thus, a significant improvement of European citizens' quality of life is expected together with an increased competitiveness of the European industry and a large contribution to meet the EU 20/20/20 energy and climate targets(2).

In this context, this paper focuses on the smarter integration of ICT infrastructures in transportation systems as shown in the figure of the front page. First, we introduce the specification of future ICT-based services that are newly requested by stakeholders of the transportation sector. This is addressed in section 2 together with an illustration of the performance limitations met when using state-of-the-art, so called 4G, ICT technologies. Then, we present in section 3 the recent initiative from the ICT sector to design the next generation, so called 5G, convergent radio access network technologies, architecture and standard capable to offer not only consumer but also professional services with stringent requirements. Finally, we will make conclusions in section 4.

2. ICT needs in transportation systems

There is a growing demand for ICT in transportation systems. On one hand, public transportation operators, especially railway operators, want to deploy an increasing range of heterogeneous communication－based services from the safety-critical ones (e.g. train control) to the passenger-oriented applications (e.g. onboard internet access).

On the other hand, public authorities would like to increase the safety level of individual vehicles and reduce traffic congestion by traffic management.

2.1 ICT for railway applications

As shown in Fig.1, the various ICT-based railway applications result in very different ICT requirements.

ICT-based train control is a key technology to accompany urbanization. It allows reducing the inter-train distance, thus increasing the train line density. Train control does not require much throughput from the ICT infrastructure but needs high reliability. To increase the passengers' safety, there is a growing interest for platform and onboard closed-circuit TVs (CCTVs) with real-time transmission to police departments. This safety-related service may have a significant impact on the throughput requirements. Onboard Internet access for passengers needs high throughput but service reliability can be relaxed.

Offering this large range of services is very challenging with existing technologies. Therefore, we have optimized the way different services are using the radio resource, prioritizing the safety-critical services while not impacting too much the throughput and latency of other services(3).

Besides, the radio spectrum dedicated for railway operators is very limited. In Europe, only 8MHz of radio spectrum have been allocated to railway operators, which are using a railway-specific 2G technology (GSM-R : Global System for Mobile communications-Railway). This obliges railway operators to envisage using also non-dedicated radio spectrum. In this context, we have evaluated the interference between a train equipped with an onboard femto base station and surrounding three-sectored macro base stations of a public cellular network using the same radio spectrum through computer simulations(4).

Moreover, trains are operated in adverse environments for radio propagation. For instance, the mobility of existing trains can reach 350km/h (500km/h with future trains), which directly reduces the achievable transmission throughput. We have evaluated the impact of

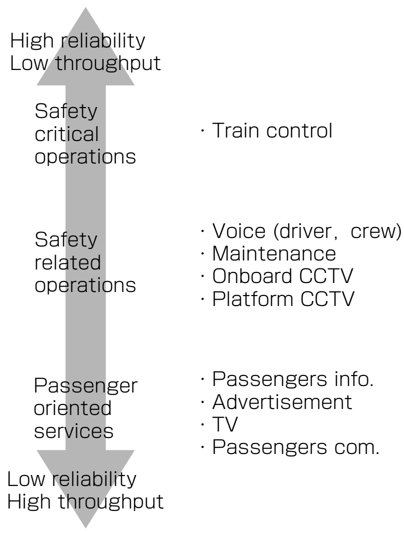

Fig. 1 Requirements of ICT-based railway services

mobility on the achievable throughput of a 4G technology with the parameters in Table 1, Fig. 2 confirms the strong throughput loss resulting from train high mobility.

From the above analysis, it is clear that up-to-date ICT with better integration needs to emerge in order to fully satisfy the railway transportation sector.

2. 2 ICT for individual vehicle applications

Today, autonomous vehicle safety is increased gradually, mainly for high-end cars, thanks to advanced driving assistance services using embedded radars, cameras or sensors. In the future, cooperative safety among vehicles is expected thanks to Cooperative Intelligent Transportation Systems (C-ITS). With car-to-car or car-to-infrastructure communications, it will be possible not only to adapt in real-time each car movement depending on its environment but also to optimize the traffic load on the road infrastructure so as to make sure each driver arrives in a minimum time to its destination.

Although a dedicated radio spectrum has been reserved in the 5 GHz band for C-ITS applications, the economic viability of deploying a dedicated ICT infrastructure along every road is still unclear. Using an already deployed cellular infrastructure may offer a realistic alternative.

In Fig.3, C-ITS target applications are presented together with their real-time requirements. With requirements of transmission latency lower than 50ms, active safety is hardly achievable by using a 4G technology. Such extremely low latencies can be achieved with a dedicated IEEE 802.11p short range communication system. However, the cost of the deployment of such a system hinders the development of C-ITS.

In order to take benefits from public deployments and economies of scale brought by 4G ICT, a next-generation, called 5G, ICT must be designed satisfying not only consumer requirements but also professional requirements.

Table 1 Evaluated parameters for a train-to-railroad transmission

Radio parameters	Value
Carrier Frequency	800MHz
Bandwidth	4 MHz
Antenna configuration	1 × 1, 1 × 2
Modulation	QPSK, 16QAM, 64QAM
Turbo code rate	1/10, 3/10, 5/10, 3/4, 5/6
Speed	0, 350, 500km/h
Number of trains	4 trains per cell

QPSK : Quadrature Phase Shift Keying
QAM : Quadrature Amplitude Modulation

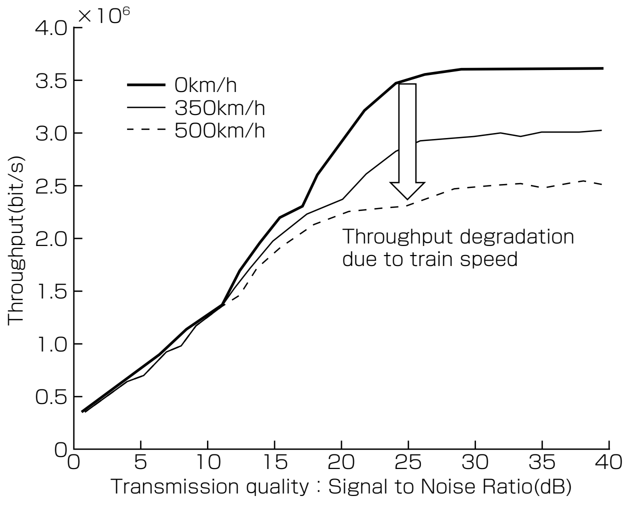

Fig. 2 Impact of train mobility on ICT throughput

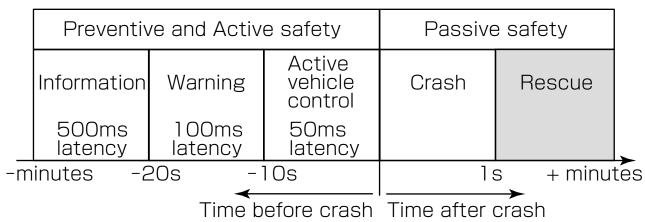

Fig. 3 C-ITS target applications

3. Next Generation ICT Infrastructure for Smarter Communities

In order to satisfy throughput and latency requirements for consumer and professional use, the 5G ICT has to support spectrum bandwidth at least five times larger than state-of-the-art 4G ICT. Due to spectrum scarcity, 5G ICT will make the best use of existing radio technologies and rely on the design of new radio technologies in less crowded bands above 6GHz.

Fig.4 depicts the concept for 5G ICT currently developed in European Union (EU). The 4G radio technology should be updated in order to cope with frequency bands as high as 30GHz and a completely new radio technology should be developed for millimeter wave bands above 30GHz. In addition to these new technologies, existing 4G, WiFi and satellite components will be integrated in 5G ICT. Optical and satellite backhaul will provide base stations with efficient connection to the core network whatever their location.

Challenges for 5G are numerous. For consumer services, it should avoid the data crunch expected for 2020, considering the current progress of data communication on public networks. For professional services, it should offer robustness to mobility and short transmission delays. Energy and operation/maintenance efficiency is also a main concern. Finally, resilience, for instance to natural disasters, should also be addressed. Table 2 lists the main challenges as defined by the 5G Private Public Partnership (5G-PPP) in EU.

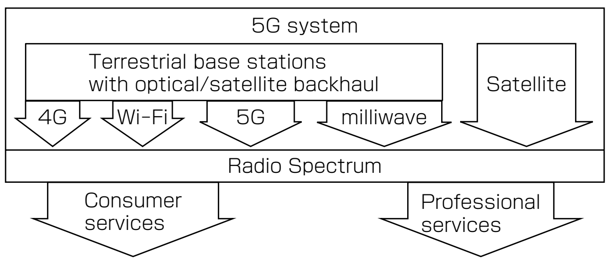

Fig. 4 5G system vision

Table 2 Key Performance Indicators for 5G ICT

	Challenges	Purposes
Main key performance challenges	1000x total throughput 10x user throughput	Solution to the data crunch, immersive experience
	~1ms service level latency	Delay-sensitive applications like C-ITS, tactile internet
	-90% energy consumption	Reduction of the 4.5% part of ICT in global energy consumption
Main key System challenges	Quality of service	Improved Quality of Experience (QoE) for differentiated services
	Manageability	Reduction of manual management
	Hardening	Intrinsic robustness to attacks or natural disasters
	Flexibility	Seamless mobility across networks
	Evolution	Transparent migration and future development

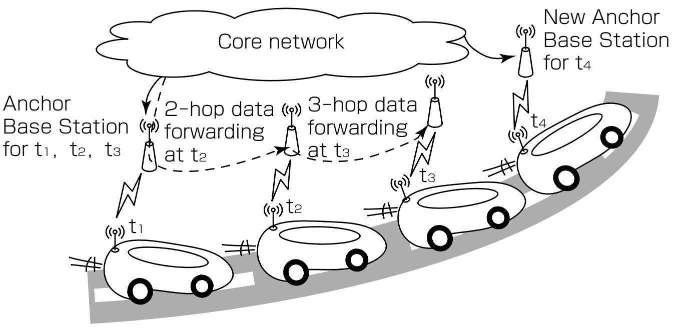

Fig. 5 Optimized anchor selection for high mobility

In order to offer the expected high throughput to the users, the 5G network infrastructure integrates many very-low-range cells, i.e. small cells, implying strong cooperation between base stations. However, the smaller the cells, the more difficult the network management of a moving vehicle.

A key issue in mobility is the selection of the anchor base station receiving user data from the core network and forwarding it to the base station actually serving data to the user. As shown in Fig. 5, we have developed solutions to efficiently select the anchor base station in order to avoid too frequent anchor changes due to mobility, which may lead to connection loss, and data forwarding with too many hops, which saturates the network links between base stations.

Besides, the cooperation between base stations involves frequent signaling between cooperating cells and put a strong burden on the core network. In this case, signaling methods which achieve efficient cooperation are needed(5) while maintaining reasonable burden on the core network(6).

4. Conclusion

In this paper, we have presented the European trends on Smart Communities with a focus on the integration of the transportation and ICT sectors. Whereas 4G ICT technology shows performance limitations, the promising 5G set of technologies will allow new professional-and consumer-oriented applications to improve safety and comfort in transportation.

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