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Tactile Internet of Everything and New Applications

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Abstract
The ecosystem for smart city initiative in future will entail several entities including Internet of Things (IOT), very fast and reliable mobile access, and ubiquitous computing. Particular areas of impact include data acquisition, data communications, data analysis, and data reliability and security. The requirements entail challenging targets of increasing Internet connectivity to 100+ B, capability to transfer of 80+ ZB data, and capacity of 1Tb/s/Km^2 by 2025. This paper focuses on the technological advances that will address the challenges and enable the realization of the tactile IoT. The paper initially focuses on network and access. Access will be based primarily on use of 5G wireless standard with its support for operation in a very wide range of frequencies, Multiple Input Multiple Output (MIMO), small cell architectures, and direct sensor to sensor communications. The rationale for a fundamental shift from current SQL based relational databases to pattern based distributed graph databases with integrated views of networking, component, security, and user interface is covered. With the impending end of life of Moore's law, the use of quantum computing at sub-atomic level, biological computers, and optical computers as computing engines is emphasized. The transitions from the current technologies in areas of networking, access, computing, databases, spectrum, security, and position awareness systems are identified.

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I. Introduction

A representative example of the focus of the future Information and Communications (ICT) arena is the smart city with its associated foundation of Internet of Things (IoT) and ubiquitous computing. These require significant and traumatic advances in a range of technologies and fundamental shift in the development environment. This paper identifies the major technology constituents encompassing the Smart city application and indicates related areas of advances needed to address the challenges. Section 2 contains the major constituents of the Smart City application and its impact on the network and access. Major technology requirements are identified and the challenges in meeting them are discussed. This is followed by identification of the major enablers to address these challenges in subsequent sections. Sections 3, 4, and 5 focus on three main technology areas, i.e., network and access, storage, and computing respectively. A key area of interest is not only what technology advances are needed but also how the architectures and networks will transition effectively from the current framework to the future systems. This is covered in Section 6. This is followed by concluding remarks in Section 7. The list of key references then follows.

II. Technology Constituents and Network Attributes

The Ministry of Urban Development of the Government of India published a very comprehensive foundational paper on the Smart City and its areas of coverage as summarized in Figure 1 [GOI]. Most of the areas have direct impact on Information and Communications Technologies (ICT). E-governance has a major impact in terms of accessibility by large number of citizens to electronic access to several interconnected databases in support of information exchange between the citizenry and the government. The areas of waste, water, and energy management requires large number of sensors and monitoring devices interconnected with each other and with central resources for processing, storage, and communications. Urban mobility is a typical example of IoT with massively connected mobile entities and real time data transfer and distributed processing. Similar inter connections and network are needed for enhanced health services of the future. So the future applications in several domains require deployment of broadband networks and use of smart devices and agents. Broadband mobile networks result in increase of connectivity of smart devices and sensors and entail various technologies including cable, optical fiber, and wireless networks. Increase in and distribution of collected embedded intelligence and advanced capabilities like spatial and temporal intelligence becomes an imperative. Additional impacts include provision of real time access to information needed to perform increasingly complex dynamic tasks and privacy-preserving secure access of data from disparate smart city sensor and data acquisition systems. The trend in current technology advances is already well on its way to meet these challenges and requirements. There is continued dynamic increase in computing power and storage capacity, data transmission speeds, and network connectivity. Systems supporting real time gesture recognition and transmission are being prototyped. Advances in artificial intelligence, robotics, and digital natural language comprehension are key enablers and are receiving significant research attention. With the technology reaching the limits of Moore's law miniaturization, there is relentless and continued progress in nanotechnology and manipulation of information at sub-atomic at and biological cell levels. The key areas with considerable impacts are the network and access, Database architectures, and computing.

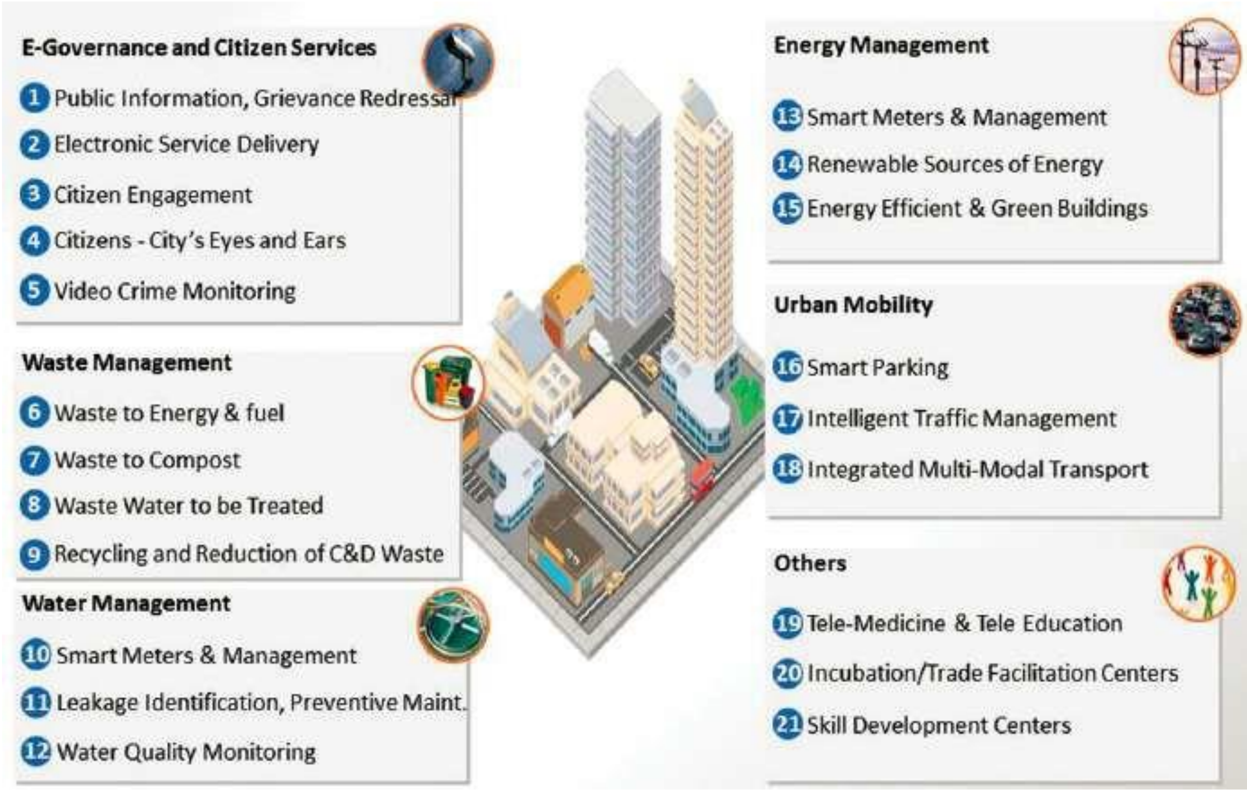

Figure 1: Smart City and its Constituents (GOI)

III. Network and Access

The Network to support the smart city application needs to be a super-efficient mobile network which should support reduction of unit cost of data transport at roughly the same rate as the rise in volume of data demand. IN future, the traffic will be dominated by machine to machine communications with stringent requirements on end to end latency and high security and integrity. Hence the name Tactile IoT. The traffic will largely be supported in a contiguous manner by densely clustered small cells resulting in a super-fast mobile network. Significant traffic is also expected to be peer to peer instead of through shared and centralized resources like base stations and core. In order to support consolidation and multiplexing of traffic, a hybrid converged fiber-wireless network is envisaged for support of data access speeds of up to 10 Gbit/s via use of Millimeter wave bands (20 – 60 GHz). The network will ultimately support 1 Tbit/Km^2 capacity in 2030 timeframe. The proposed 5G Wireless standard [NGMN], [NOKI] is being designed specifically to meet such requirements. (See Figure 2)

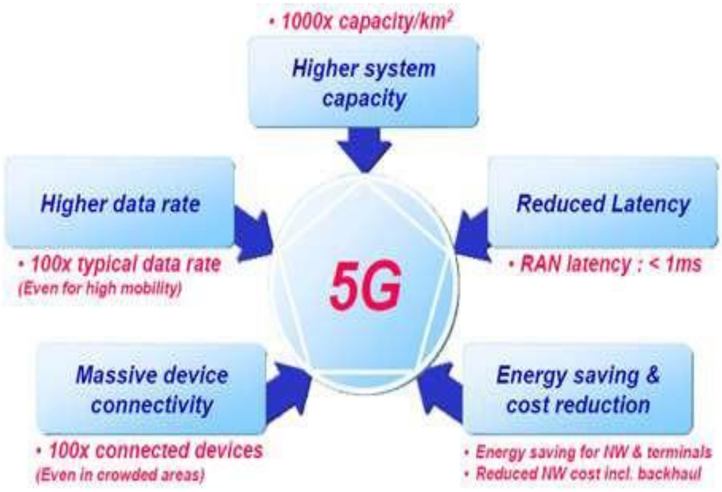

Figure 2: 5G Wireless Requirements

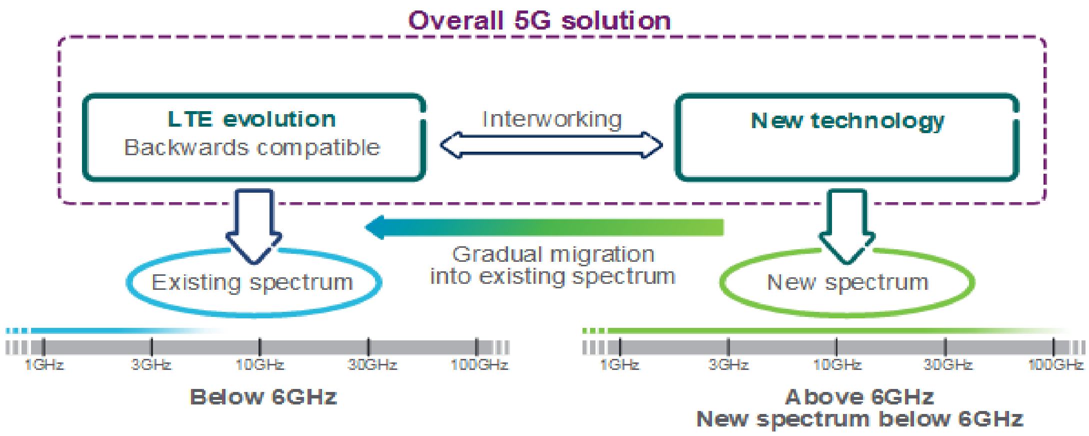

Figure 3: 5G Wireless Operating Frequency

The range of operating frequency for 5G Wireless is expected to extend at the low end from the traditional wireless spectrum at 700 MHz to as high as 100 GHz at the high end as indicated in Figure 3. Initially 5G systems will augment existing 3G and 4G systems and will be deployed in the millimeter wave spectrum using low range densely populated cell stations consistent with operations at such high frequencies. Over time, existing 3G and 4G networks will transition into 5G networks to exploit its enhanced performance and capacity.

Table 1 Technology Transitions

Item	Current	Future
Technological Growth	Evolutionary	Transformative and Disruptive
Architectures	Silos of Systems	Multi Dimensional
Network Addressing	IP v4 (32 bit)	IP v6 (128 bit) with mobility, security, and auto-configuration
Access	Primarily human interactions; Video and Data traffic	Massively connected; dominated by machine to machine traffic
Access Frequencies	700 MHz – 6 GHz	700 MHz – 100 GHz
Spectrum Allocation	Static and regulated	Dynamic and Efficient
Databases	Localized. Relational	Distributed, Graph
Computing	Moore's Law and VVLSI	Sub-atomic and Biological building blocks
Global Positioning	Location based with limited accuracy	Perceptive, Awareness based for enhanced connectivity and accuracy

IV. Storage and Database

Large Database aspects entail distributed storage and communications and will be inherent part of future applications. The key attributes are data acquisition, data communications, and data integrity. Data acquisition will be supported by sensor technologies and communications systems. They entail ultra-low power design techniques. Data communications involve content distribution, multimedia networking, Quality of Service (QoS), policy based networking, congestion control, and routing challenges. Communication is also driven by technologies, regulations, and policies. The communications performance will utilize advanced wireless sensor networking, scheduling theory, and algorithms. Advanced Data and System integrity covering confidentiality, integrity, authentication, and access control will be implemented . The technology will address privacy mechanisms for big data processing, security issues in cloud computing, and mobile and cloud security. The key technology for future storage and communications is the advanced graph database architecture [ROBI], [STOR]. It will allow representation of complex data and abstract concepts and also the representation of the connections inherent in IoT. It will possess instant correction capabilities and will be able to manage structured and unstructured data. New prediction models will be developed for reducing the dimensionality of diverse data. It will be necessary to distill essential information in the form of a reduced set of prioritized variables that characterize the outcome. In current SQL based relational databases, entities are defined but their relationships are derived indirectly. The graph databases of future will identify patterns and store hidden relationships among the data variables.

V. Computing Platforms

Having reached limits of Moore's Law, computing technology is exploring three areas for providing traumatically significant improvements in processing power [NATI]. These areas are Optical Computing, Quantum Computers, and Biological Computers Optical computers utilize crystals and metamaterials to control photon light particles. Metamaterials are materials synthesized from composite materials like plastics and other materials. These have smart properties like manipulating electromagnetic and light waves and have potential applications in smart computing. A quantum computer will exploit laws of quantum mechanics to perform certain information processing tasks in a significantly fast and efficient manner. Biological computing is based on use of nanobiotechnology and utilizes systems of biological derived molecules, e.g., DNA or proteins to perform computational calculations for storing, retrieving, and processing data.

VI. Transitions to New Technologies

In addition to the three main areas of advances mentioned above there are other major areas which will push the envelope of current knowledge for meeting the smart city and tactile IoT applications. These include Dynamic spectrum allocation, IP addressing, global positioning systems, and human machine interface. These are summarized in Table 1. The technology transitions cover a range of areas from Technology Growth to human machine. Future technology growth will be driven by transformative and disruptive growth in contrast to what is currently considered primarily as evolutional growth. Architectures will be multidimensional based not only on multi- technical areas but also account on societal, legal, and human aspects. The ubiquitous 32 bit IPv4 protocol will essentially be replaced by the 128 bit IPv6 standard which also includes support for mobility, security, and auto-configurations. As mentioned earlier, the network will have to support efficiently and effectively the dominant machine-to- machine traffic in contrast the current access which is generally optimized for video and data traffic. The 5G wireless will extend the spectrum usage to 100 GHz. A key area of significant advancement will be usage of dynamic spectrum allocation for efficiently utilizing the scarce spectrum resource. The transitions for databases and computing have already been mentioned in the earlier sections. Perceptive, awareness based global positioning systems for enhanced connectivity and accuracy will replace current global positioning systems with their limited accuracy. Human machine interface will be transformed from the current electromechanical interface to one based on gesture recognition.

VII. Conclusion

Advances in Technology will be driven by future. Smart City and Tactile IoT applications. The challenging requirements will require super-efficient and fast broadband networks with intelligent sensors, mobile access, high security, and dynamic, distributed, and connected databases. The traffic will primarily be based on machine-to-machine communications. 5G wireless standard will be the primary access mechanism and graph databases will be the primary storage entities. Engineers and Scientists will push the envelope of spectrum usage and efficiency and perceptive global position awareness systems will be the norm.

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