For limited circulation

Technology Digest

Bulletin of telecom technology

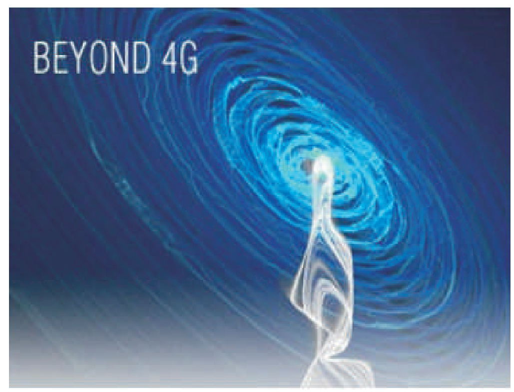
Issue 20, April 2013

Telecom Regulatory Authority of India

In this issue

Beyond 4G

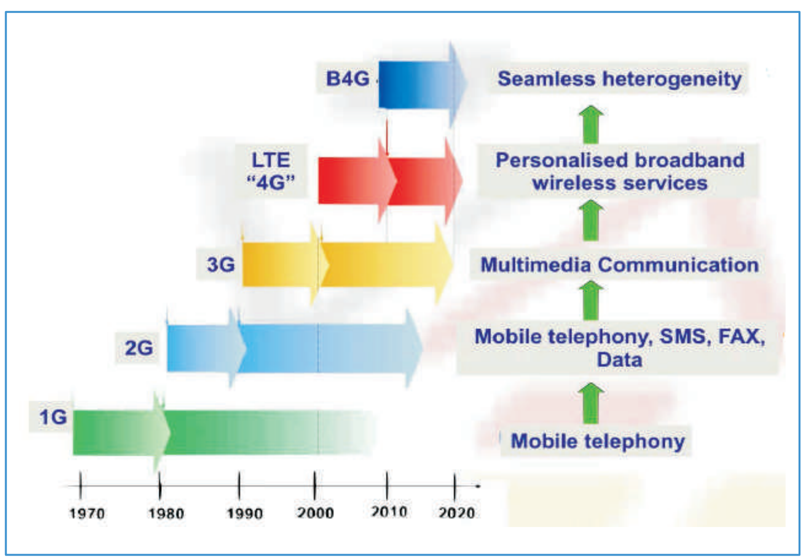
The world has seen a lot of changes in the realm of telecommunication. With the advent of tablets, smart phones etc. the data consumption pattern of users is changing rapidly. Moreover traffic on wireless networks has been nearly doubling annually and around 2020, the data consumption is expected to be about thirty times of the present volume. As a result 4G technologies will not be able to support this rapidly increasing data demand in future. The data rate offered by 4G technologies to stationary users is 1 GB/s and that to mobile users is 100 Mb/s. The supported data rate is expected to increase much more in the technologies beyond 4G. Spectrum is a finite resource. In present wireless systems, frequency licensing and efficient spectrum management are key issues. Technologies beyond 4G are expected to bring forth efficient solutions to these problems. In the technologies beyond 4G, spectral efficiency is expected to be very high due to opportunistic use and sharing of spectrum by cognitive and smart radios. Cognitive radio technologies in 5G and beyond will allow spectrum sharing among multiple transmissions by reallocating temporarily unused portions of the spectrum.



Moreover the wireless network's environmental impact is becoming an increasingly important consideration. Improving the energy efficiency of network components, such as base stations and access points, not only cuts CO2 emissions but, also reduces operational expenses, lowering the cost per bit. This is important, considering the expected traffic and throughput growth up to 2020.

Future networks will feature ubiquitous networking, higher spectral efficiency and consistent performance over the entire coverage area, energy efficiency for improving consumer experience and reducing the carbon footprint of users, reduced latency etc. These technologies will have extraordinary data capabilities which will be capable of handling unrestricted data and voice volumes, creating a new revolution in mobile market and the communication industry.

Currently, Mobile operators are busy with deployment of 4G technology namely, LTE-advanced or WIMAX 802.16m.



At present, technologies beyond 4G have not been given any official name in any particular specification or in any official document made public by standardization bodies such as 3GPP, WiMAX Forum, or ITU-R. New standards to provide the exact specifications for technologies beyond 4G are being worked out by standardization bodies, which are considered to be a part of the technologies under the 4G umbrella. Probably technologies beyond 4G will be defined in the near future and their deployment will start at around the year 2020.

Technical Aspects

Key concepts suggested in different scientific papers discussing technologies beyond 4G wireless communications are:

Pervasive networks

The next trend over the horizon beyond mobile Internet is called "ubiquitous networking" or "pervasive networks". This involves the use of radio frequency identification (RFID) technologies and their integration with other information and communications technologies, which has dramatically accelerated in the last few years with rapid reductions in microchip size and cost [3].

Pervasive networks providing ubiquitous computing: The user can simultaneously be connected to several wireless access technologies and seamlessly move between them. This may also be a feature of future 4G releases. These access technologies can be 2.5G, 3G, 4G, or 5G mobile networks, Wi-Fi, WPAN, or any other future access technology. In 5G, the concept may be further developed into multiple concurrent data transfer paths.

Future networks will be deployed more densely than today's networks as shown in below figure. Due to economic constraints and site availability issues, networks will become significantly more heterogeneous in terms of transmit power, antenna configurations (number, height and pattern of antennas), supported frequency bands, transmission bandwidths and duplex arrangements. Radio network nodes will vary from stand-alone base stations to systems with different degrees of centralized processing, depending on the availability of front-haul and backhaul. Diverse radio access technologies will need to be integrated, with any combination of LTE, HSPA+, Wi-Fi and Beyond 4G radio access technologies. Last but not least, the allocated spectrum will be more fragmented and may even be shared among CSPs according to new license models.

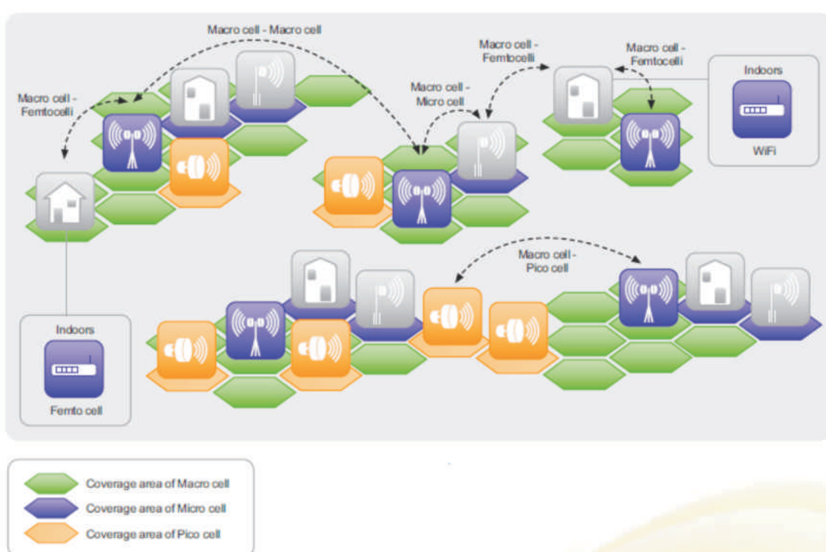


Figure1: Heterogeneous Networks with a myriad of multi-radio cell layers

Group cooperative relay

With the development of the MIMO (multiple input multiple output), the system achieves relatively higher throughput and reliability in a wireless network. This is a technique that is being considered to make the high data rates available over a wider area of the cell. Currently data rates fall towards the cell edge where signal to interference ratio is poor. This technology is clearly advantageous for base station side but disadvantageous for the mobile station due to size and power constraints of the mobile devices. An alternative to this is group cooperative diversity. In cooperative communication, source transmits data to the destination while neighbouring user (relay user) also receives the transmission. The relay user processes and forwards this message to the destination and received signals at the destination are combined. The signals are transmitted along different physical paths giving a spatial diversity. Mostly, cooperative diversity can be performed two ways.

1. **Amplify-and-Forward**: In this relay station receives the signal, amplifies it and then forwards it without decoding. This system is useful when relay node is power limited. Major drawback of this system is that it also amplifies the noise at relay node.

2. **Decode-and-Forward**: In this relay station receives the signal, decodes it, and then forwards it to the destination. We can add error correcting code at relay node. This is only possible if relay station has enough power.

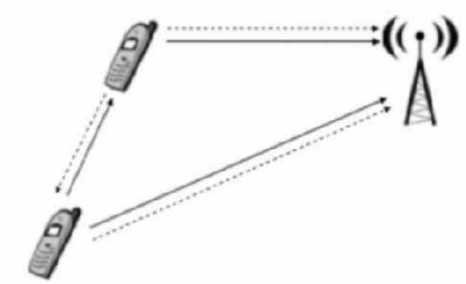


Figure2: Group Cooperative Communication

Cognitive radio technology

Cognitive radio technology is known as smart-radio: allows different radio technologies to share the same spectrum efficiently by adaptively finding unused spectrum and adapting the transmission scheme to the requirements of the technologies currently sharing the spectrum. This dynamic radio resource management is achieved in a distributed fashion, and relies on software-defined radio.

Most of today's radio systems are not aware of their radio spectrum environment and operate in a specific frequency band using a specific spectrum access system. Investigations of spectrum utilisation indicate that not all the spectrum is used in space (geographic location) or time. A radio, therefore, that can sense and understand its local radio spectrum environment in order to identify a temporarily vacant band of spectrum and use it, has the potential to provide higher bandwidth services, increase spectrum efficiency and minimise the need for centralised spectrum management. This could be achieved by a radio that can make autonomous (and rapid) decisions about how it accesses spectrum. Cognitive radios (CR) have the potential to do this. CR is an amalgamation of software defined radio (SDR) and intelligent signal processing (ISP). Combining the facets of radio flexibility, intelligence and spectral awareness, a full CR will adapt itself to changes in the environment, its user's requirements and the requirements of other radio users sharing the spectrum (in time and space). A full CR will also use long-term analysis to learn about its environment and its own behavior [5].

If cognitive radio technology is used in 5G systems, then it would enable the user equipment / handset to look at the radio landscape in which it is located and choose the optimum radio access network, modulation scheme and other parameters to configure itself to gain the best connection and optimum performance.

Cognitive Radio Spectrum Sensing techniques are given below:

1. Continuous Spectrum Sensing: In this system spectrum occupancy will be monitored continuously, and cognitive radio system will use the spectrum on a non-interference basis.

2. Monitor for Empty Alternative Spectrum: When the primary user returns to the spectrum, then cognitive radio system must have an alternative spectrum available so it can switch the secondary user on it.

3. Monitor type of transmission: The cognitive radio must have knowledge of transmission used by users so that interference can be ignored.

Mobile Ad-hoc Network (MANET)

Mobile Ad-hoc network is a self configuring wireless network that does not rely on fixed communication infrastructure. MANET is an autonomous collection of mobile users (nodes) that communicate over relatively low bandwidth wireless links. The member nodes share the same random access wireless channel, and the network topology changes dynamically due to node movements. Media access control (MAC) and routing for MANET are challenging as they have to adapt quickly to provide addressing and channel access control and select paths for network traffic. The network is decentralized, where all network activity including discovering the topology and delivering messages must be executed by the nodes autonomously, i.e., routing functionality will be incorporated into mobile nodes. The primary challenge in building a MANET is equipping each device to continuously maintain the information required to properly route traffic. Such networks may operate by themselves or may be connected to the larger Internet.

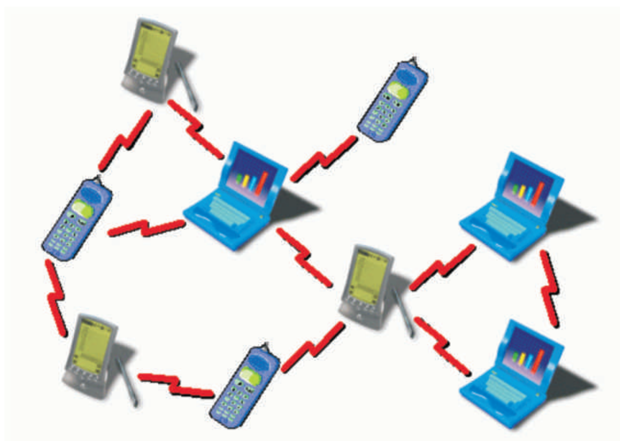


Figure3: MANET

Some MANETs are prone to disconnection due to motion of network nodes, network sparsity and sporadic density. This type of network experiences high delay and is referred to as delay-tolerant network (DTN) or disruption tolerant network – characterized by non-existence of instantaneous end-to-end routing paths. In this context, conventional MAC and routing schemes may fail because of volatile links and lack of complete path between the source and the destination.

MANET has the following features:

Autonomous terminal: In MANET, each mobile terminal is an autonomous node, which may function as both a host and a router. In other words, besides the basic processing ability as a host, the mobile nodes can also perform switching functions as a router. So usually endpoints and switches are indistinguishable in MANET.

Distributed operation: Since there is no background network for the central control of the network operations, the control and management of the network is distributed among the terminals. The nodes involved in a MANET should collaborate amongst themselves and each node acts as a relay as needed, to implement functions e.g. security and routing.

Routing Protocols: Routing protocols must take a store-and-forward approach. Packets are stored in network nodes and upon communication opportunities, incrementally moved from their origins towards their destinations. Routing protocols can be categorized into forwarding-based or flooding-based. Forwarding-based approach does not replicate a message is less wasteful of the network resources. Unfortunately, packet forwarding is problematic for frequently disconnected links, because it drops packets if a next-hop route is not immediately available. This results in a low packet delivery rate in DTN. Flooding-based approach, on the other hand, replicates messages within the network and allows the existence of multiple copies. This redundancy increases the probability of successful delivery of packets and thus achieves a high packet-delivery rate. Other MAC and routing protocols utilizing the knowledge of speed and position of network nodes are being researched [18].

Dynamic network topology: Since the nodes are mobile, the network topology may change rapidly and unpredictably and the connectivity among the terminals may vary with time. MANET should adapt to the traffic and propagation conditions as well as the mobility patterns of the mobile network nodes. The mobile nodes in the network dynamically establish routing among themselves as they move about, forming their own network on the fly. Moreover, a user in the MANET may not only operate within the ad hoc network, but may require access to a public fixed network (e.g. Internet).

Fluctuating link capacity: The impact of high bit-error rates of wireless connection might be more profound in a MANET. One end-to-end path can be shared by several sessions. The channel over which the terminals communicate is subject to noise, fading, and interference, and has less bandwidth than a wired network. In some scenarios, the path between any pair of users can traverse multiple wireless links and those links can be heterogeneous.

Light-weight terminals: In most cases, the MANET nodes are mobile devices with small computation power, small memory size, and limited power supply. Such devices need optimized algorithms and mechanisms that implement the computing and communicating functions.

Flat IP Architecture

Existing telecom networks are in hierarchical ways, where traffic is aggregated at BSC/RNC and then routed to gateways. Flat IP architecture will reduce the burden on aggregation point, and traffic will directly move from base station to the media gateways. Driving the market towards this idea is widespread acceptance of the fact that today's hierarchical architectures, conceived in the circuit-switched era, won't be able to efficiently support mass-market, real-time IP services in the medium term. With the shift to lower-latency flat networks that comprise fewer network nodes, mobile operators can align infrastructure capabilities with emerging application requirements and benefit from substantially greater flexibility in how core and access networks are integrated. Key to the emergence of flat networks is advanced base station equipment that integrates functions such as radio control, header compression, encryption, call admission control, and policy enforcement. In the mobile core, the requirement is for "access gateway" products capable of supporting multiple radio technologies simultaneously on a common hardware and software platform, scalable to multiple cost and traffic profiles.

Notable points in a flat IP network are as follows:

- All access technology specific portions are contained in the BTS, with no centralized components that are access technology specific.
- Access technology specific signaling remains at the edge, signaling is dealt with as soon as it arrives: no transmission and queuing delay to transmit to a central node. The system is more predictable because signaling operations are less dependent on a backhaul infrastructure and other (central) elements.

- The backhaul is fully IP and its operation can be kept separate from maintaining the access technologies, this enables route optimization from the edge, reduces the complexity of maintaining a cellular network and enables operator sharing of infrastructure.

- Since the central components are minimized, the possibility of system-wide disruption is also reduced in a flat IP architecture. In flat architectures, failures in specialized components are localized. For example if a BTS in a flat system fails, it can quickly re-establish itself without intervention of central nodes.

- Centralized systems are less resilient to attacks, for example if RNC or IP gateway is attacked then a large set of cell sites are affected. But in a flat IP architecture, if an I-BTS (integrated BTS) is attacked, only one cell site affected, naturally localizing the effect of the attack. Moreover, if a cell-site is attacked, it can be disabled and any neighboring cell-site can offer coverage temporarily.

Smart antennas

Another major element of any beyond 4G cellular system will be that of smart antennas. Using these it will be possible to alter the beam direction to enable more direct communications and limit interference and increase overall cell capacity.

Smart antenna technology or adaptive antenna array technology enables dynamic alterations in antenna configuration to adapt to changing transmission conditions. Smart antennas are equipped with signal processing capability to determine the direction of signal transmission and thus adapting the signal beam shape and direction using beam-forming techniques to achieve better reception, or transmission. Smart Antennas use adaptive antenna array scheme to enable the antenna to perform is beam formation and signal direction detection.

Figure5: Smart Antenna

Beam Division Multiple Access

In the mobile communication system, limited frequency and time resources are divided to be used among multiple users, and the capacity of the mobile communication system is limited by the available bandwidth and tolerable time delay. The capacity of future mobile communication systems must increase in order to serve the ever increasing data demands of the ever increasing number of mobile stations. However, since bandwidth and time resources are limited, there is a scope of a technical development, which uses resources than frequency/time in order to increase the capacity of communication system. Beam Division Multiple Access proposes frequency and time sharing among different mobile stations located at different angular positions with respect to the base station by serving each mobile station with a different signal beam. Smart phased array antennas with advanced beam forming capabilities are required to achieve BDMA. In the case when two or more mobile stations use the same beam, their signalling must be done orthogonally in either frequency space and/or time space. This way, the communication system not only utilizes the frequency and time dimensions but also utilizes the space dimension, enabling the reuse of the precious frequency and time slots.

A suggested algorithm to set up BDMA in a communication session goes as follows: initially the mobile station and the base station are unaware of their relative positions and velocities. The mobile station must determine its position and velocity and transmit this information Omni-directionally to the serving base station. Based on this information, the base station determines appropriate beam characteristics suitable of the mobile station and transmits the downlink beam with the determined time/frequency/space characteristics. The beam characteristics adapt dynamically to the changing channel characteristics and changing relative position and velocity of the base station and mobile station. This not only improves the system communication capacity, but it may also help solve the signal deterioration problem at the cell edge due to path loss and the problem of high inter-cell interference. Radiation efficiency of the communication system can be improved by suitable matching of the radiation patterns of the base station and mobile station signal beams.

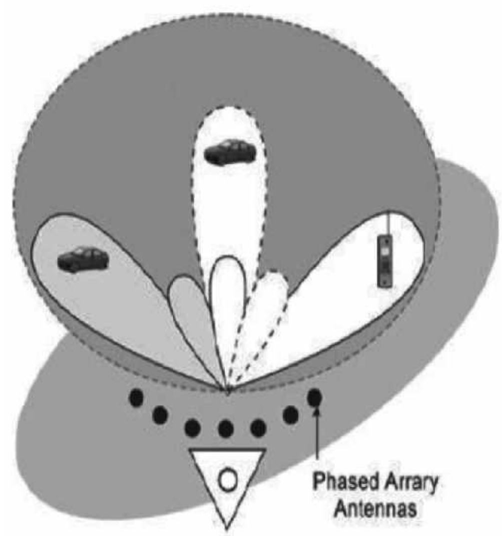


Figure6: Beam Division Multiple Access

Vandermonde-subspace frequency division multiplexing (VFDM)

VFDM is a multiplexing scheme that allows the co-existence of macro-cells and cognitive radio small-cells in a two-tiered LTE/4G network. VFDM allows for interference cancellation in overlay networks such that a secondary network can operate simultaneously within a primary network, on the same frequency band. VFDM can be applied to block transmission systems with a guard time (or cyclic prefix) over frequency selective channels. It achieves zero interference towards the primary system by employing a special precoder that aligns the data to the null space of the interfering channel from the secondary to the primary system.

Conclusion

There have been a lot of changes in the field of communication technology. Several technologies have been discussed, many of whom are likely to be seen in the beyond 4G era of telecommunication. Technologies beyond 4G are expected to bring several advantages to the consumers, service providers and telecom equipment manufactures alike.

As the technologies march beyond 4G, we expect to witness maturity in technologies that will provide ubiquitous networking, cooperative communication, cognitive and smart radios with highly efficient spectrum usage, MANETs, expansion of the Flat IP network architecture initially coexisting with the current hierarchical network architecture and gradually replacing the latter, incorporation of smart antennas and BDMA, and overlay networks using VFDM.

Finally, in nutshell technologies beyond 4G are expected to support demands for higher data rates from a huge user base, provide excellent connectivity and quality of service across the entire coverage area, support ubiquitous networking and roaming, be highly energy efficient, provide highly reliable communication system with high spectral efficiency and capacity and low infrastructure deployment and up-gradation costs.

References: There are many to be individually acknowledged, the primary ones are cited here:

1. "2020: Beyond 4G Radio Evolution for the Gigabit Experience", NOKIA SIEMENS NETWORKS,2011
2. "2020:The Ubiquitous Heterogeneous Network -Beyond 4G", NOKIA SIEMENS NETWORKS,ITU Kaleidoscope 2011
3. http://www.itu.int/osg/spu/ip/chapter_two.html
4. http://pet.ece.iisc.ernet.in/pallapa/Ubi-Management.pdf
5. http://stakeholders.ofcom.org.uk/binaries/research/technology-research/cograd_main.pdf
6. http://www.antd.nist.gov/wahn_mahn.shtml
7. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5671838&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5671838
8. http://www.mediateam.oulu.fi/publications/pdf/92.pdf
9. "A Review on 5G Technology", SuvarnaPatil et al , IJEIT, January 2012
10. "5G: Future Mobile Technology-Vision 2020", Saurabh Patel et al,International Journal of Computer Applications, September 2012
11. www.radioelectronics .com
12. "5G Technology – Redefining wireless Communication in upcoming", Akhilesh Kumar Pachauri et al, International Journal of Computer Science and Management Research, Aug 2012
13. "5G TECHNOLOGIES – AN ANECDOTE OF NETWORK SERVICE FOR THE FUTURE", Professor T. Venkat Narayana Rao, Journal of Global Research in Computer Science, July 2011
14. "Key Concepts and Network Architecture for 5G Mobile Technology", Pratap Singh, IJSRET, August 2012.
15. 'Evolution to 5G Wireless with Mobile Cloud Applications'- Li-Chun Wang, National Chiao Tung University, Dept. of Electrical and Computer Engineering Hshinchu, Taiwan.
16. http://www.itu.int/osg/spu/ip/chapter_two.html
17. http://pet.ece.iisc.ernet.in/pallapa/Ubi-Management.pdf
18. Liang Dong, *Opportunistic media access control and routing for delay-tolerant mobile ad hoc networks*, Springer, May, 2012

Published by: Telecom Regulatory Authority of India
Editorial responsibility: TD Division, TRAI
Contributions, comments and suggestions: tdra@trai.gov.in