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Mobile Clouds: Technology and Services for Future Communication Platforms

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Introduction

- Over the past decades, mobile communication has evolved from a predominantly voice-driven format to connect individuals to an enabler of a host of new paradigms that support always-on everywhere communications.
- Similarly, the individual human-to-human communication of the early days has given way to a now **mobile-to-any communication** paradigm, whereby “any” could refer to other fixed or mobile devices (autonomous or under direct human supervision), including those offering **cloud-based services**. Fueled by these new communications opportunities, we witnessed an immense growth of mobile devices and **network traffic** in ever expanding networks.

Introduction

- it is assumed that an increased amount of mobile data will be delivered through **mobile multimedia streaming, such as in Internet Protocol television (IPTV).**
- The ever-growing gap between the increase in forecast mobile traffic and what can actually be delivered in today's networks has led to a proactive stance toward reengineering the mobile network to cope with the additional traffic demands. One approach is the use of small cells that support an increased number of users in small geographic areas, such as **femtocells** .

Introduction

- With the socially driven content consumption of today’s mobile users, quite often popular content is consumed by a multitude of users in close proximity. Without downstream optimizations, each user taxes the mobile network – new communications paradigms favor the utilization of mobile-to-mobile or device-to-device communication (M2M or D2D) in a cooperative fashion to maximize downstream data availability while reducing the burden on the delivering networks.
- **Such approaches aim at exploiting likely correlations of socially connected users: geographical location, similar interests, and so on**

Introduction

- Over time and with increased network-centric client-server communications, this paradigm has developed into the term “cloud.” In past decades, this approach was also referred to as AAS, or “as a service,” whereby one of the more commonplace references was SAAS, or Software As A Service . Software vendors offered time-charged access to software, which was no longer on client premises and allowed for easier deployment as needed and simpler usage-based costs for clients.
- However, the perception of mobile devices has shifted from a user-centric intelligent multimedia communication vehicle to simply a “resource” that can offer a plethora of services in terms of computational power, storage, and context.

5.2 The Mobile Cloud

- Cloud-based resource sharing has witnessed a tremendous growth period and now comprises a multitude of potential resources that can be shared either within a specific cloud or amongst interconnected clouds.
- we can distinguish between different resources based on **being tangible / intangible, limited/ unlimited, context-specific/general**, amongst other alternatives, that can form a pool of virtual resources to be shared in the cloud.
- Some examples **that have emerged are cloud computing, cloud storage, and cloud gaming.**

5.2 The Mobile Cloud

- Example of mobile cloud : we consider the imaginary BORG weather service provider, which uses collectively gathered measurement data to improve on traditional forecasting methods.
- The app periodically (infrequently) reports back to the weather service provider with the location of the device and the measured values. Being able to determine nodal positions superimposed with the barometric pressure allows the BORG weather service now to determine which nodes would be outside and hence able to provide a reliable barometric pressure value (and not, e.g., height inside a building).

5.2 The Mobile Cloud

- Combining the measurements of all participating users in a certain geographic area (say a predicted bad weather area) allows the BORG weather service to calculate the impact of the weather on the nodes' locations and in turn provide feedback.
- The BORG weather provider itself relies on another company to perform the complex computational superimposition of measurement points and locations, weather predictions, and so on. The external company in turn provides computational resources to the BORG provider.

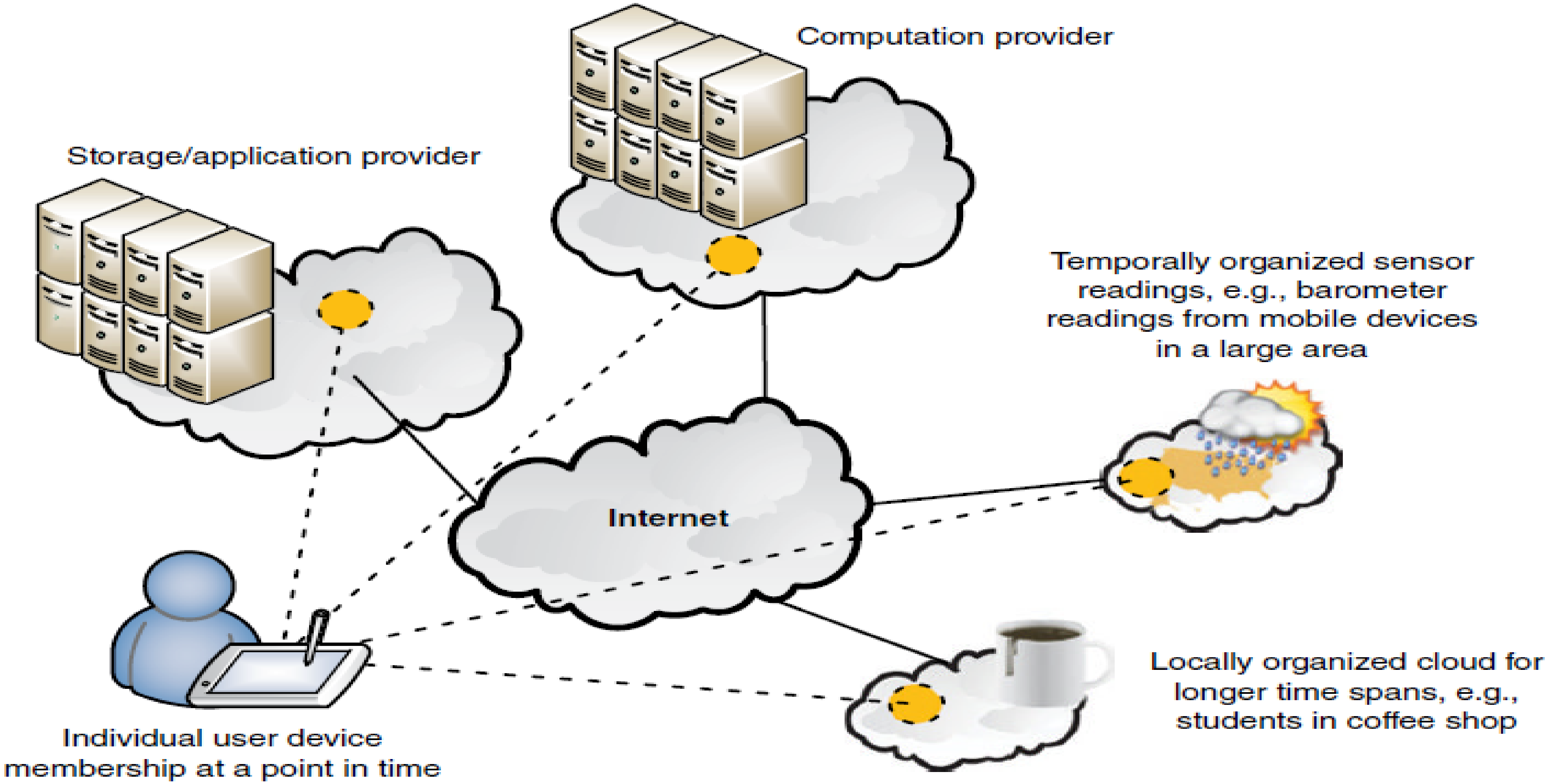


Figure 1 BORG weather service provider example and various spatio-temporal cloud formations to provide sensor readings, grouped uploads, and computational resources to implement the service.

5.2 The Mobile Cloud

- Typically, cloud-based resources in the end provide an abstracted service from the service provider to the service consumer (e.g., application) that results in abstracted resources.
- The underlying service-enabling functions are transparent to the consumer and offered by individual nodes that constitute the cloud as a cloud resource pool.
- In a cloud-computing scenario, for example, individual processing nodes provide computational power to the cloud's resource pool, which is in turn available to the service consumer. However, the location of the nodes providing the service or their physical implementations is irrelevant to the consumer, as only the access to the cloud's shared resource pool is relevant.
- This allows the service provider to optimize nodal numbers, placements, configurations, and scheduling of resource availabilities (to name but a few) decoupled from client requests.

5.2 The Mobile Cloud

- mobile cloud computing has emerged, which introduces mobile devices as nodes accessing services in cloud-based resource pools.
- the individual cloud-based nodes that provide the remotely accessed services feature capabilities that are magnitudes higher than requested, for example, processing capabilities or storage capacities.
- the trade-off between saved mobile CPU cycles and the increased communications costs of uploading tasks and retrieving results has gathered research interest.

5.2 The Mobile Cloud

- virtual cloud pool including mobile devices offers opportunities to provide additional resources that are only feasible in a mobile context, such as wireless connectivity, sensors, actuators, and other different functionalities and capabilities .
- This inclusion is similar to the expansion of the network-centric paradigm of client-server communications into a peer-to-peer architecture, which, nonetheless, still relies on the client server principals by requiring individual nodes of the P2P network to simultaneously function as clients and servers (or clients and service providers of a conglomerated resource cloud).

5.2 The Mobile Cloud

- **An additional benefit in enlarging** the common concepts of individual service provider–based cloud resource offerings is the added resilience for negative events . **Distribution of cloud resources**, such as geographically into multiple data centers, adds redundancy and allows for additional service scaling.
- The inclusion of mobile devices themselves in the resource pools of the different potential cloud services allows for greater flexibility.

- We provide an overview of the different resource pools in Figure 2 with a focus on (i) the cloud perspective and (ii) the individual contributor, using smartphones as examples.
- The degree and time of availability of each resource can in turn be controlled through explicit user configuration or through (semi-)automatically configured rules that allow different degrees of granularity in the control.

5.2.1 User Resources

- Individual, whereby an individual user controls one or multiple devices and sets the operational parameters not just for the individual device, but the entirety of devices, similar to the notion of a "personal" cloud.
- Group levels incorporate multiple users or owners/operators, which now include a social aspect that requires additional considerations.
- Universal resources include the potential of common control of available resources in the context of the cloud. The most likely scenario here is that infrastructure is provided by the society at large, which in turn is accessible by everyone .

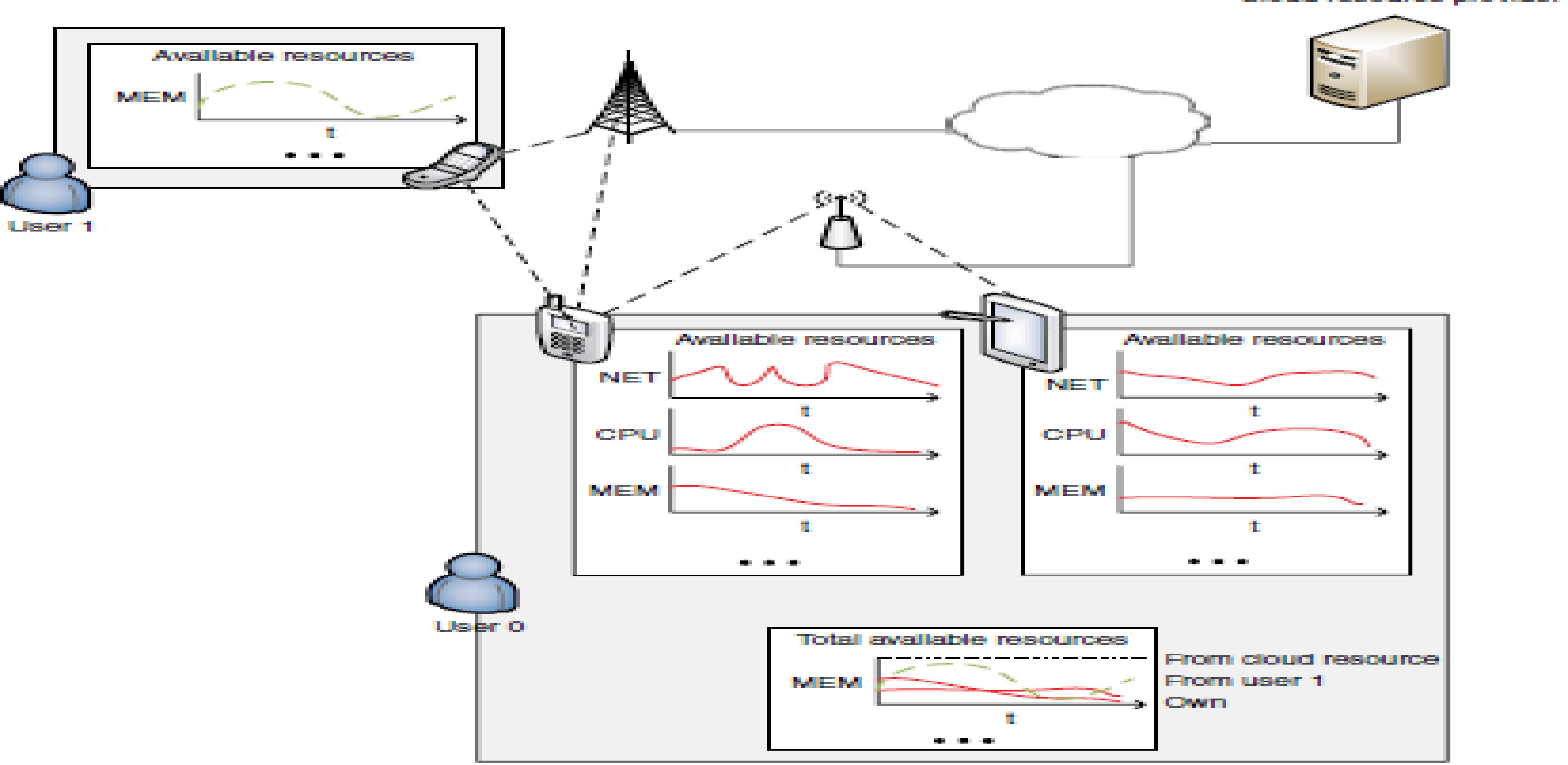


Figure 2 :Examples for mobile cloud participants and their sharing of resources. User 0 has access to individual own resources, shared resources from User 1, an resources that are enabled through cooperation with a cloud-based resource provider, here assumed to be storage.

5.2.2 Software Resources

- Operating systems define the overall operation of a cloud node, such as a mobile device, including the low-level interfacing possibilities. Examples include Linux, iOS, or Android operating systems.
- Non-serviceable software is typically present on most mobile devices and can be utilized in a user-transparent manner for user-interfacing devices, such as smartphones. **An example of such an application is CarrierIQ**
- User space applications can be installed based on user needs and device application scenarios.

5.2.3 Hardware Resources

- Computational, such as the processing units (CPUs), graphics processing units (GPUs), or specialized digital signal processors (DSPs), up to field-programmable gate arrays (FPGAs);
- Storage, such as volatile memory (e.g., RAM) and non-volatile longer-term storage memory (e.g., flash memory);
- Sensors, such as light, location, temperature, microphone and camera, to name but few;

- Actuators, such as the display, a flash, notification lights, speakers, or even directly connected servo motors
- Energy, such as the battery in mobile devices, solar panels, or even continuously provided power from the power grid in plugged-in scenarios.
- **resources can be available in a continuous fashion, or be limited in amount and/or time, depending on the scenario .**

5.2.4 Networking Resources

- Cellular communications (from 2G to the current 4G) provide the always-on, always connected approach initially, with the providers limiting service coverage.
- Wireless LANs have been popular from the early days of mobility, when larger devices, such as laptops, were the common computing platform in mobile contexts.
- Bluetooth has been a popular addition to mobile devices for more than a decade. Current advances to the standard that reduce the amount of power needed for small amounts of data to be exchanged (Bluetooth Low Energy, BLE) in an almost sensor network approach allow for a broad range of future application scenarios.

- Infrared (IR) / visible light communications (VLC) represent optical air interfaces in deviation to the other, radio frequency–based communications means.
- Near Field Communication (NFC) has gained significant traction and is becoming a common addition to smartphones. A typical application for NFC in mobile devices is the push for mobile payment systems that incorporate cellular connected devices into the value chain, such as ISIS or Google Wallet.
- Wired interfaces can be present in some mobile devices to allow plugged communications, either directly or through the use of extensions (dongles).

Definition

- **Cloud computing** refers to the use of networked infrastructure software and capacity to provide resources to users in an on-demand environment. With cloud computing, information is stored in centralized servers and cached temporarily on clients that can include desktop computers, notebooks, handhelds and other devices. Cloud computing exists when tasks and data are kept on the Internet rather than on individual devices, providing on-demand access. Applications are run on a remote server and then sent to the user.
- **Mobile cloud computing** is the form of cloud computing in combination with mobile devices. Mobile devices are increasingly becoming an essential part of human life as the most effective and convenient communication tools which is not restricted by time and place. However, the mobile devices are facing many challenges in their resources (e.g., battery life, storage, and bandwidth) and communications (e.g., mobility and security).

Mobile Cloud Computing (MCC) architecture

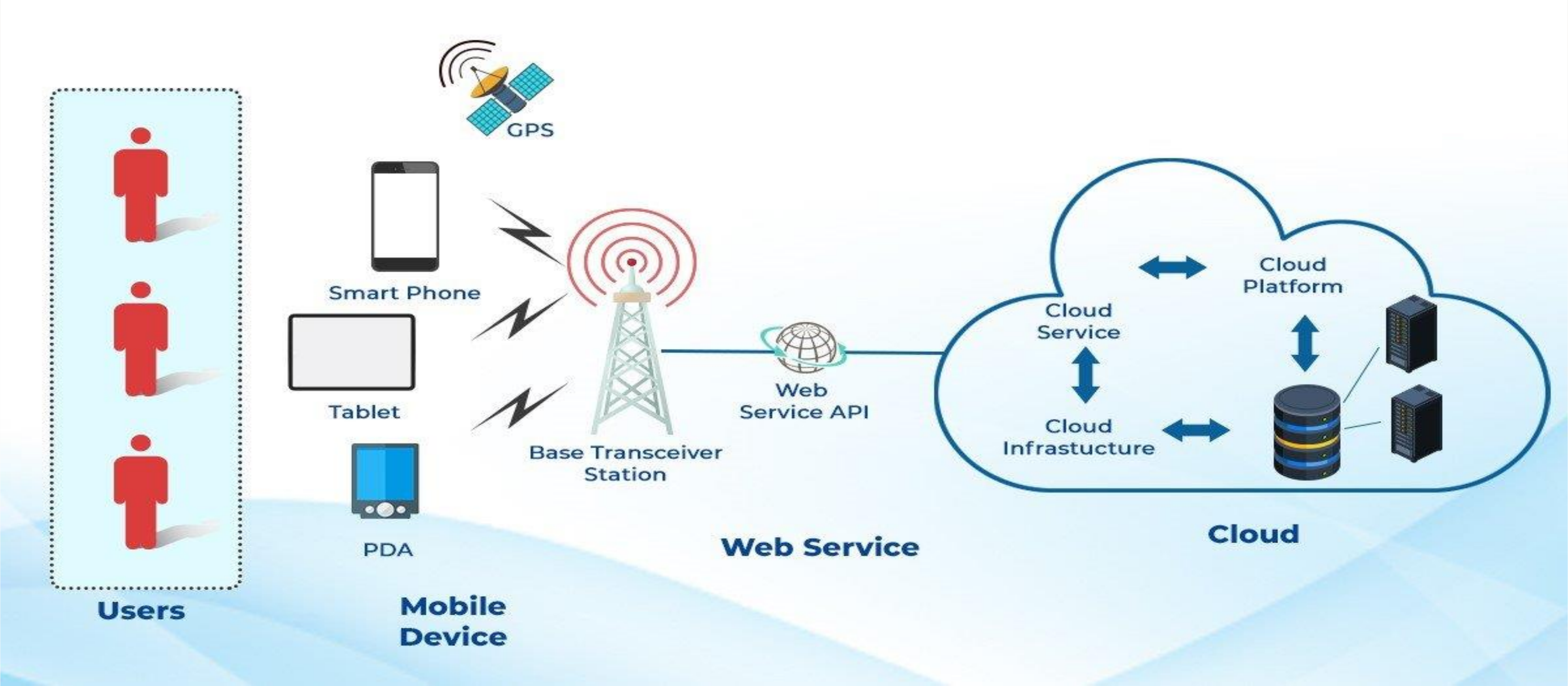


Figure 3: Mobile Cloud Computing (MCC) architecture

Mobile Cloud Computing (MCC) architecture

- Mobile devices are connected to the mobile networks via base stations that establish and control the connections and functional interfaces between the networks and mobile devices.
- Mobile users' requests and information are transmitted to the central processors that are connected to servers providing mobile network services.
- The subscribers' requests are delivered to a cloud through the Internet.
- In the cloud, cloud controllers process the requests to provide mobile users with the corresponding cloud services.

Cloud Service Architecture

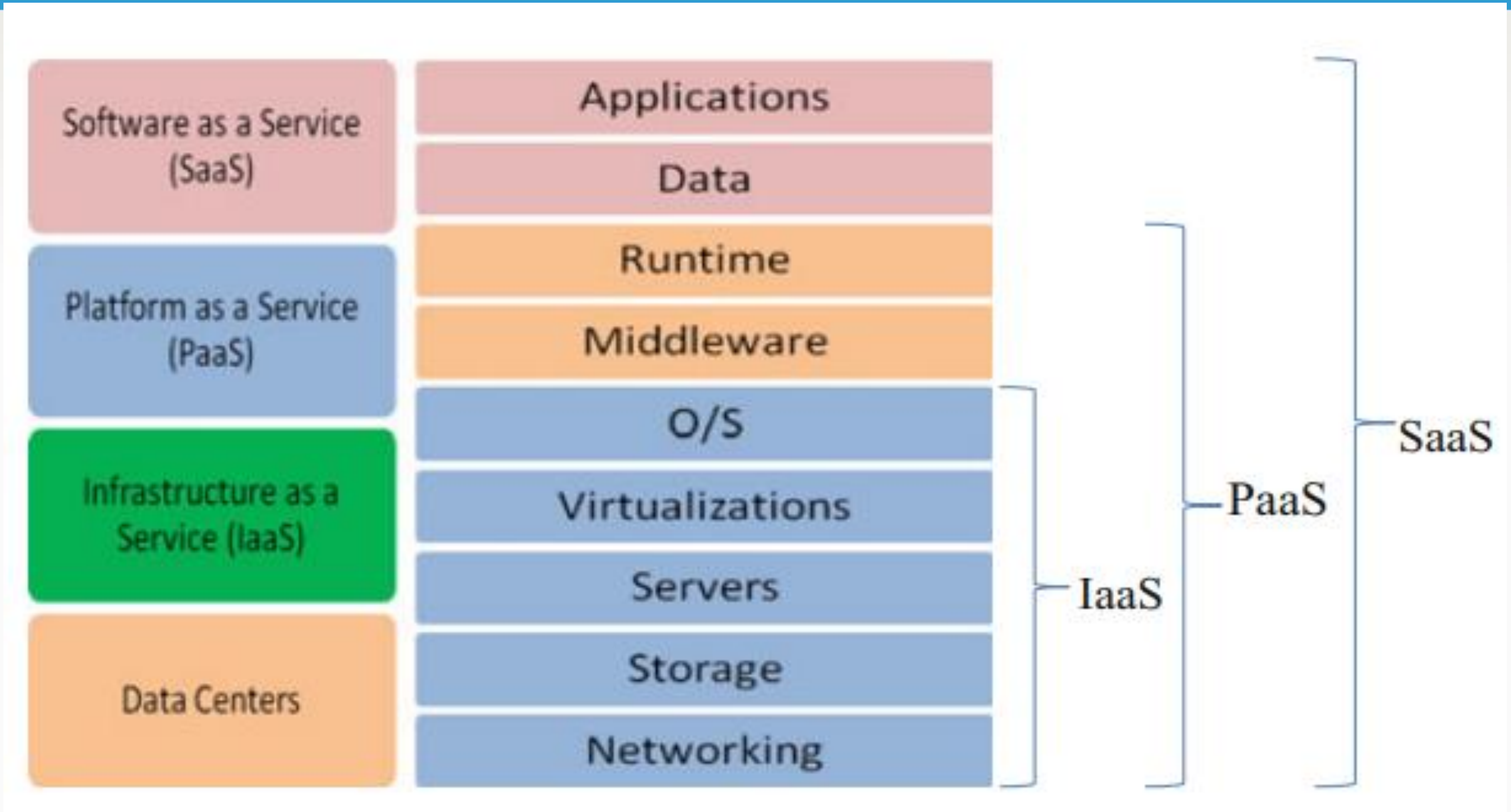
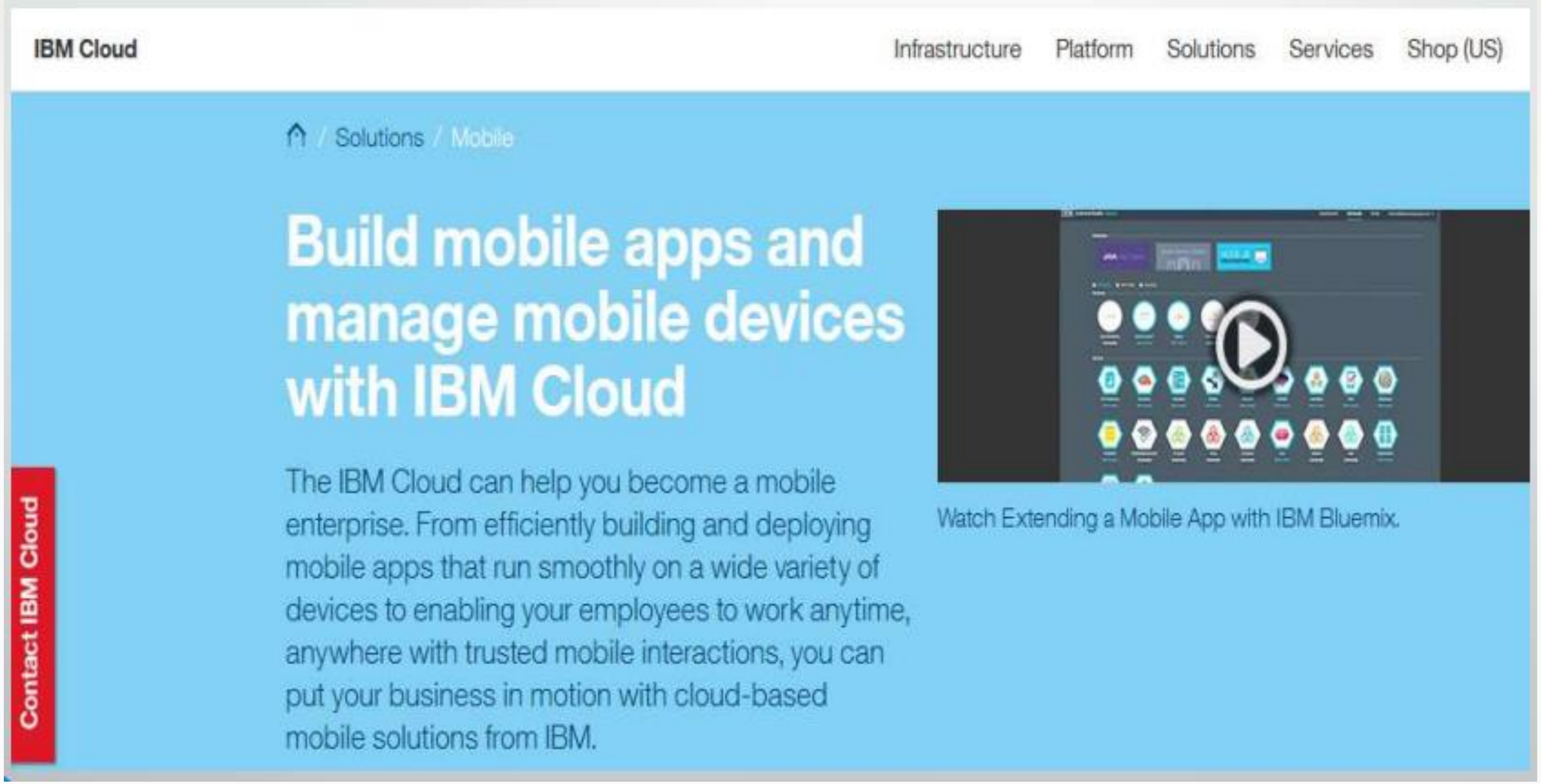


Figure 4: Cloud service architecture

IBM Mobile Cloud Service



Amazon Mobile Cloud Service

5.3.2 Wireless Technologies

- individual **nodes** communicate using **short-range** wireless links in addition to being connected to a **long-range link, such as cellular or access point networks**

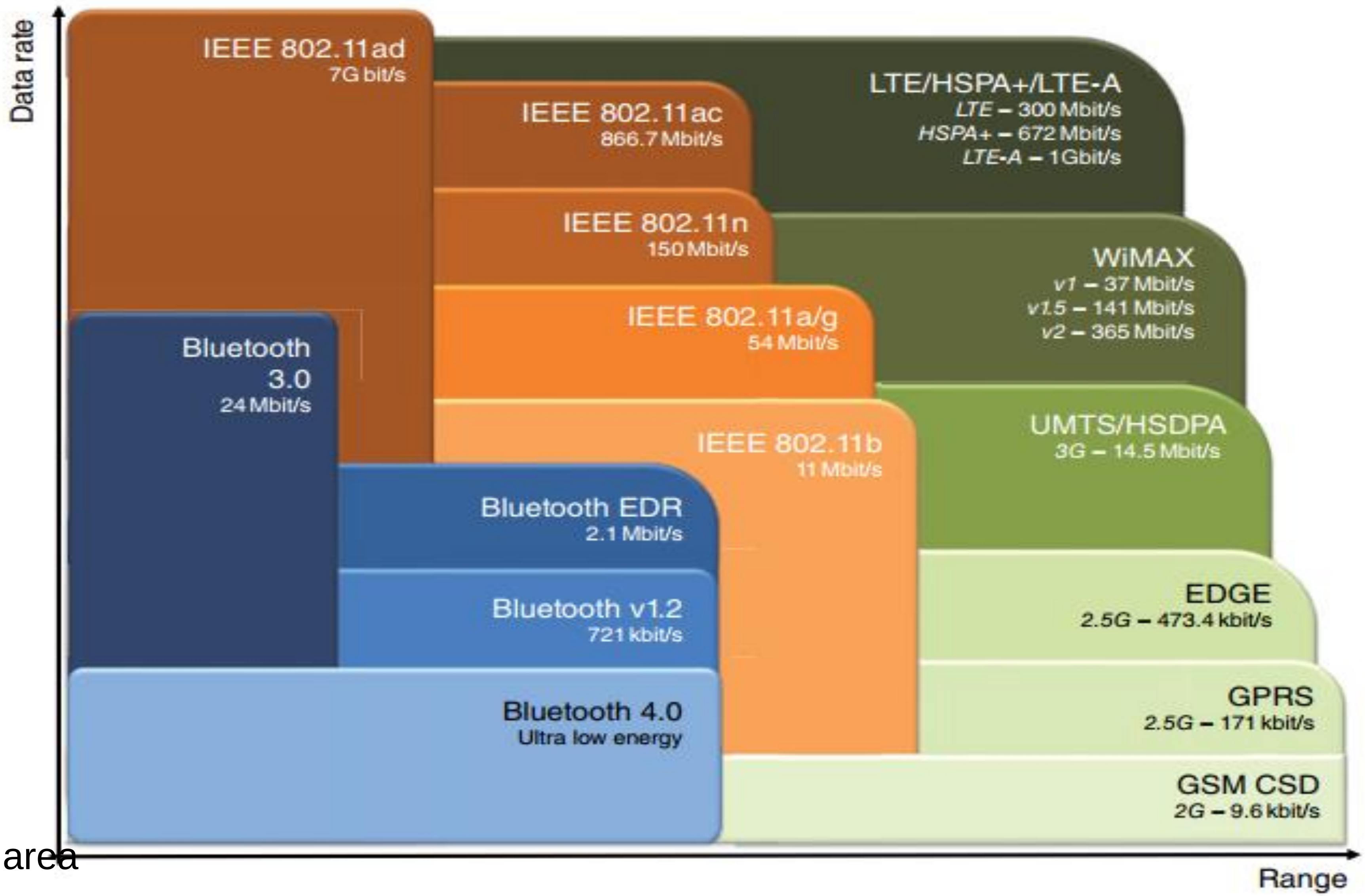
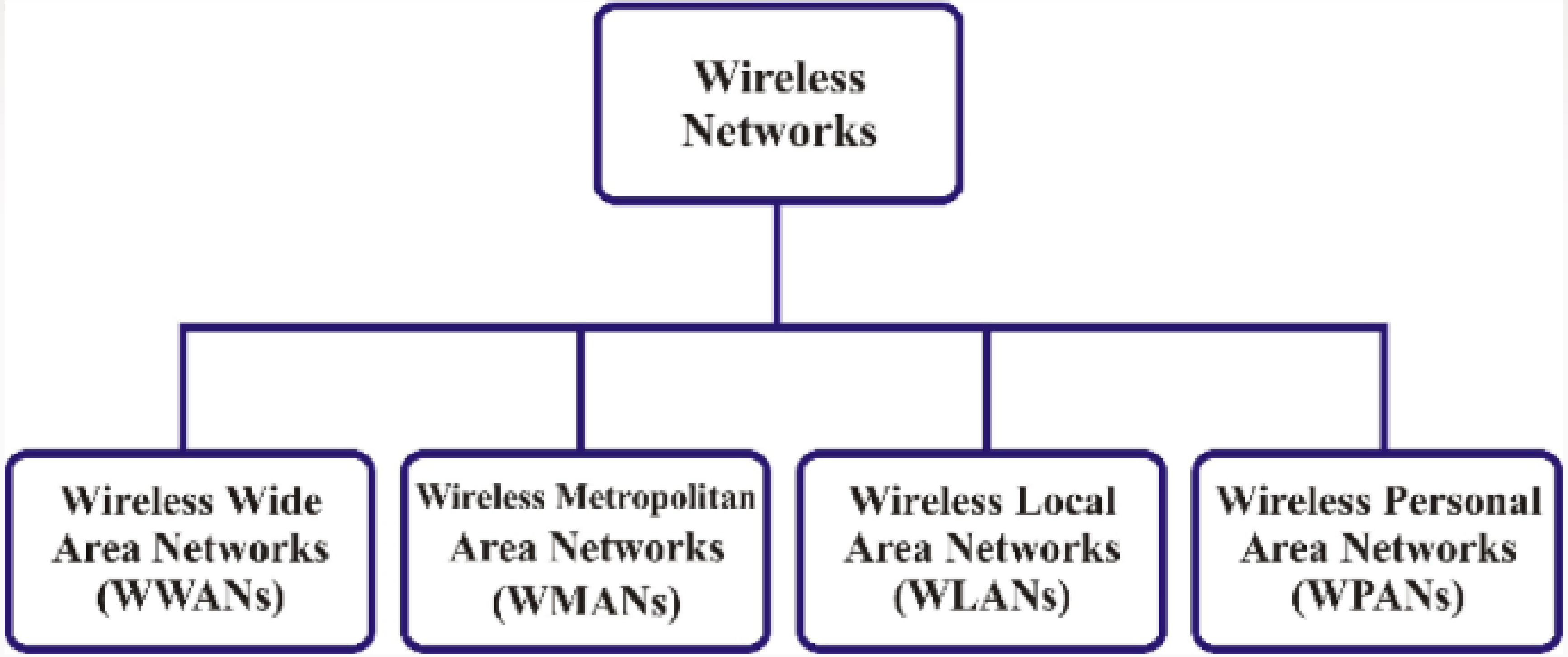


Figure 5 Overview of wireless technologies from short-range to wide area

5.3.2 Wireless Technologies



5.3.2 Wireless Technologies

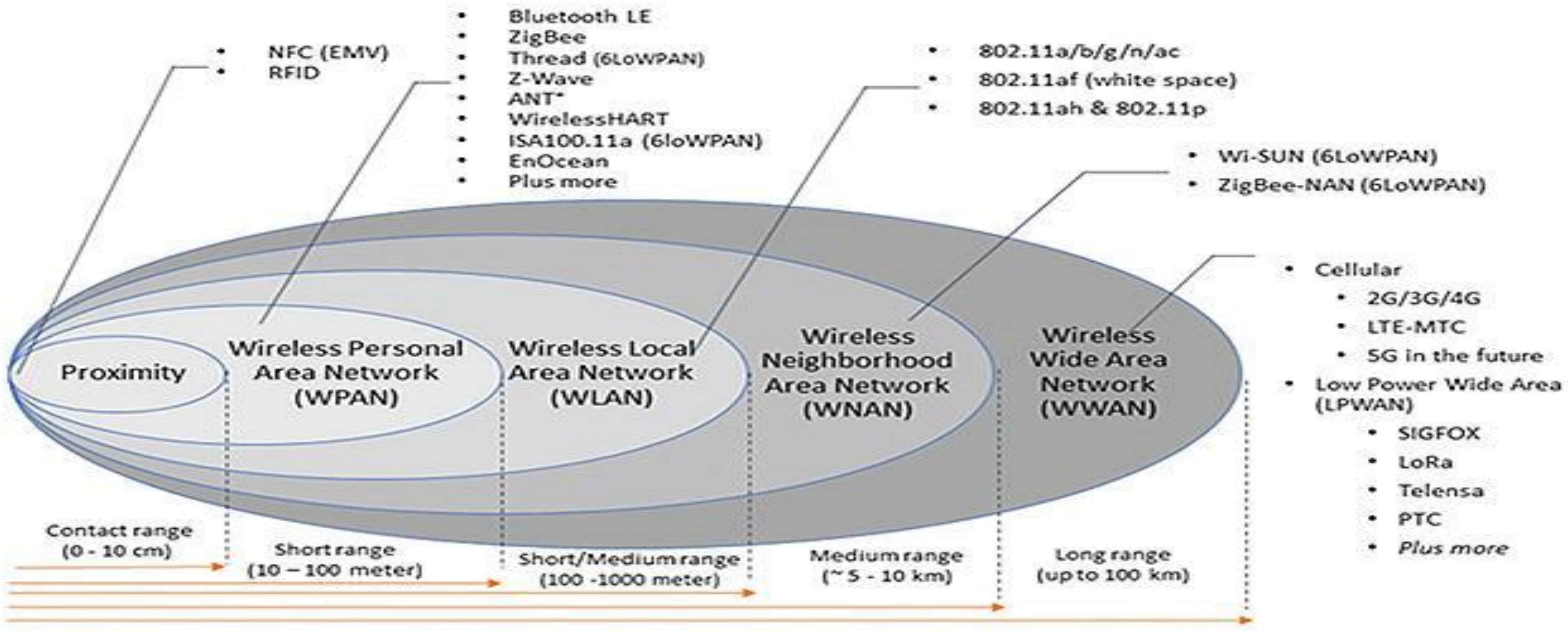


Figure 6: Wireless Technologies

5.3.2.1 Wireless Wide Area Network (WWAN) Range

- **Cellular communications** have **evolved** consistently over the past decades from **voice only to data-centric communications** with Long Term Evolution (LTE) networks, often referred to **as 4G**, becoming the norm in most cellular markets.

5.3.2.1 Wireless Wide Area Network (WWAN) Range

1G

- Not support for data communications
- FDMA
- analogue channels

2G

- **GSM**
- **circuit-switched voice** services
- first **data connections at 9.6 kbps – increase to 14.4 kbps (HSCSD)**
- Allowed channel bundling up to **four channels (for a maximum rate of 57.6 kbps**
- **upgrade was GPRS as 2.5G**
- GPRS increased the number of channels and coding schemes, which when combined with the now TDMA of GSM in a theoretical capacity of 171.2 kbps.
- moving from circuit switching to TDMA , GPRS was initiating mobile packets instead of analog voice channels
- EDGE, which increased the data rate to 473.6 kbps - 1.6Mbps .
- CDMA was introduced in 2G

5.3.2.1 Wireless Wide Area Network (WWAN) Range

3G

- GSM-based UMTS
- UMTS offers data rates around 14 Mbps using HSDPA, which is achieved using increased bandwidths.

4G

- offered by WiMAX & LTE
- data rates upwards of 500 Mbps
- CDMA

5G

- MIMO,mmWaves
- packet Network
  OFDM,BDMA
  10-30 Gbps

5.3.2.1 Wireless Wide Area Network (WWAN) Range

- For mobile cloud networking, cellular networks provide the centralized means for connecting mobile users and initially providing resources.
- LTE technology is currently being developed into LTE-A (Advanced), offering substantial performance enhancement. One novel approach in LTE-A worth mentioning is the inclusion of device-to-device connectivity using the same air interface technology used to access the overlay cellular network

5.3.2.2 Wireless Local Area Network (WLAN) Range

- Utilized communications means for smart mobile devices to date is IEEE 802.11(WiFi)
- The standard separates the medium access protocol and the physical layer specifications.
- Different technologies have emerged since the original inceptions, which include 802.11a and 802.11b, which were competing for implementations. Though 802.11a was technologically advanced, higher costs drove broad adaptation to 802.11b, which in turn became the precursor to 802.11g and 802.11n.
- For 802.11a and 802.11g, maximum data rates of 54 Mbps.

5.3.2.2 Wireless Local Area Network (WLAN) Range

- Newer versions of the standard include 802.11n and 802.11ac, which further increase the throughput through channel bundling and operational changes in both frequency bands to over 300 and 400 Mbps, respectively. With more addendums to the original standard, such as simple peer-to-peer networking, marketed as WiFi direct, the WLAN range is one of the most well-suited ranges that features decent communications overhead tradeoffs.

5.3.2.3 Wireless Personal Area Network (WPAN) Range

- The emergence of devices rather than desktops alone has sparked a significant need for individual, short-ranged data transfer between the different devices a user owns or with other devices on the go. In the following, we briefly review some of the relevant standardized approaches in the context of mobile clouds.

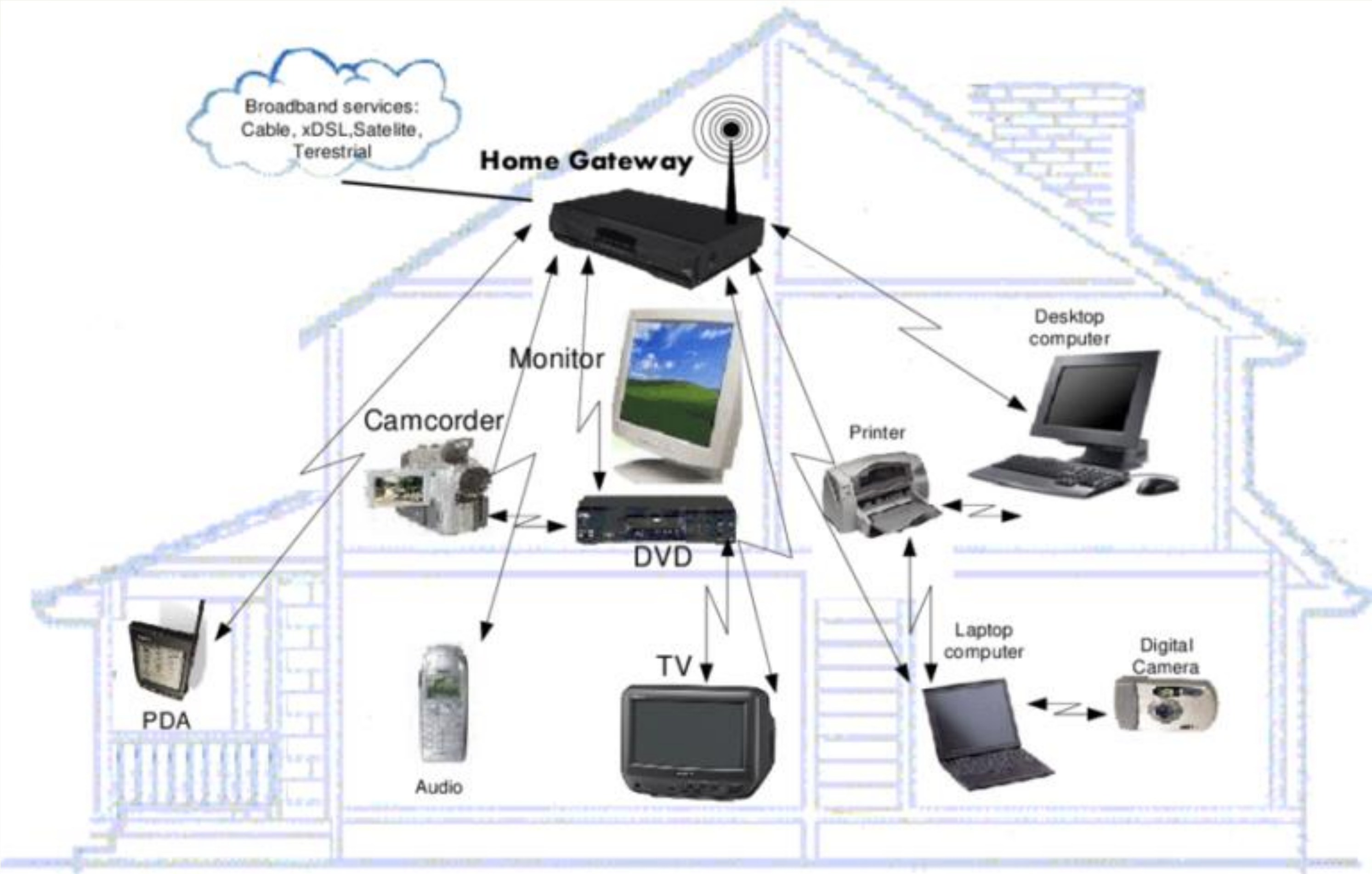


Figure 7 : Wireless Personal Area Network (WPAN)

Bluetooth

- Bluetooth operates in the 2.4 GHz band, similar to a broad range of other short- to medium-range technologies.
- The actual communication range varies and isdetermined by the Bluetooth module “Class,” which range from Class 1 (up to 100m) to Class 3 (typically 10m or less).
- The original Bluetooth design, consisting of hardware and a software stack specification , was led by an industry consortium and was afterwards standardized by the IEEE.
- Bluetooth is operating in individual picocells in a master-slave configuration, whereby one master node controls up to seven slaves and all communications are performed via the master node.

Device Class	Transmit Power	Intended Range
Class 3	1 mW	Less than 10 meters
Class 2	2.5 mW	10 meters, 33 feet
Class 1	100 mW	100 meters, 328 feet

Bluetooth

- Due to security considerations from early implementations, Bluetooth devices have to undergo an initial pairing operation that allows the communications afterwards.
- The actual communications are performed using frequency hopping creating asynchronous and synchronous channels that are accessed using Time Division Multiple Access (TDMA) with acknowledgements.

Bluetooth

- Bluetooth data rates

Version	Data rate	Feature
1.2	721 kb/s	
2.0 + EDR	3 Mb/s	Enhanced Data Rate (EDR)
3.0 + HS	24 Mb/s	High-Speed
4.0	1 Mb/s (BLE)	Bluetooth Low Energy (BLE)

- BLE is mainly targeting sensor networking with small amounts of data, such as commonly encountered in the healthcare and fitness markets, in which other technologies started to emerge. For the purpose of mobile cloud networking, the throughput and overhead offered by Bluetooth networking is rather prohibitive. However, Bluetooth connections and BLE can be utilized to efficiently configure higher throughput network connections.

IEEE 802.15.4 and Software Stacks

- In industrial and home automation scenarios, The two main standards were IEEE 802.15.4 and the main software stacks that build upon that standard, ZigBee and 6LoWPAN, While IEEE 802.15.4 can operate in the 900 MHz and 2.4 GHz bands, only the latter has gained significant traction.
- The difference from Bluetooth is the ability to form mesh or peer-to-peer networks in addition to star topologies.
- Similar to Bluetooth, different device classes exist, namely full-function devices (FFD) and reduced-function devices (RFD).
- Only FFDs can be coordinators (unlike Bluetooth). IEEE 802.15.4 utilizes CSMA/CA paired with additional beacon frames (if configured) that act as coordination and reservation entities when using a dedicated network coordinator.

IEEE 802.15.4 and Software Stacks

- ZigBee adds a full-featured protocol software stack up to the application layer with routing, security, and automation considerations. These are implemented in addition to application scenario profiles on top of the lower layers defined by IEEE 802.15.4. To allow interoperability in an all-IP configuration, the 6LoWPAN IETF working group has standardized the convergence to IEEE 802.15.4.
- Overall, **data rates around 250 kbps** are achievable in the IEEE **802.15.4** Standard at best, which makes this, similar to Bluetooth, more useful for coordination and out-of-band signaling rather than actual local data exchange when **considering the mobile cloud.**

Near Field Communications (NFC)

- NFC represent a special case, as they commonly can be considered members of the WPAN range, especially when used to communication typically small amounts of data.
- The common range for NFC communications is just several **centimeters**; it is therefore oftentimes used in **convenience scenarios**, such as **wireless payments**. While seemingly limited in communications range, however, NFC is **not inherently secure and can be eavesdropped on from a significantly large distance .**
- Implementations for IP within NFC exist as well; for example, A special scenario is **the utilization of NFC** in the context of Radio Frequency Identification (**RFID**), where NFC has found broad adoption, from logistics, for example, to secure or track items, to government-issued documents, such as passports. In the context of mobile clouds, NFC can be used to configure the connection of mobile resource providers with one another through immediate physical proximity, but not for data exchange, due to the small throughput achievable

5.3.3 Software and Middleware

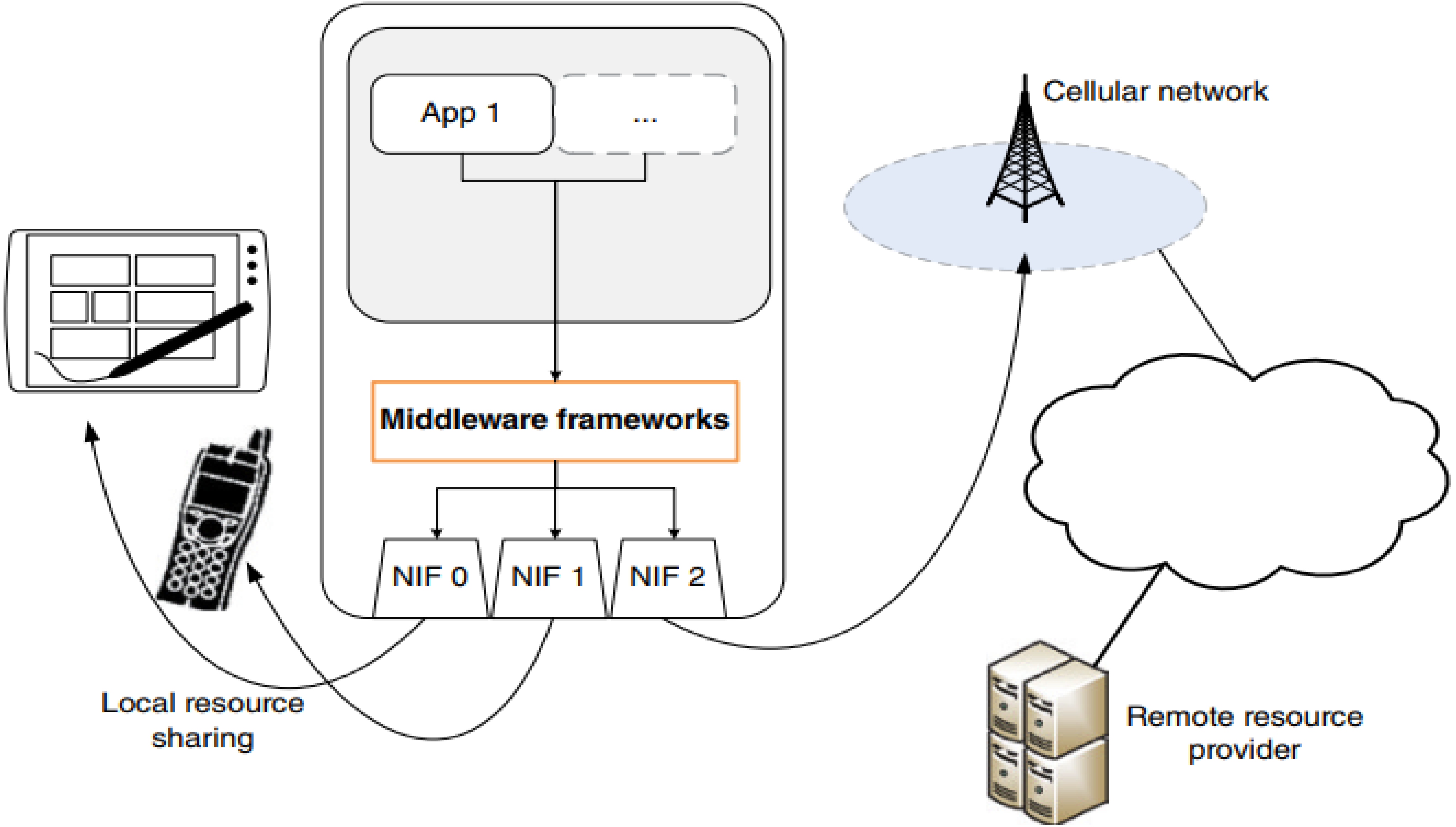
- The actual implementations and considerations of the resulting optimizations for mobile clouds oftentimes result in cross-layer approaches that are non-transparently implemented. In turn, mobile applications, for example, need to be aware of the additional opportunities, or coordination needs to take place in an interception model. These are commonly implemented in proxy services that act as middleware either on the mobile device itself or coupled with other cloud resources.
- An illustrative example is the transparent outsourcing of computationally demanding tasks from a mobile device to a cloud resource provider, which in turn performs the demanding tasks and sends the results back to the mobile device.

5.3.3 Software and Middleware

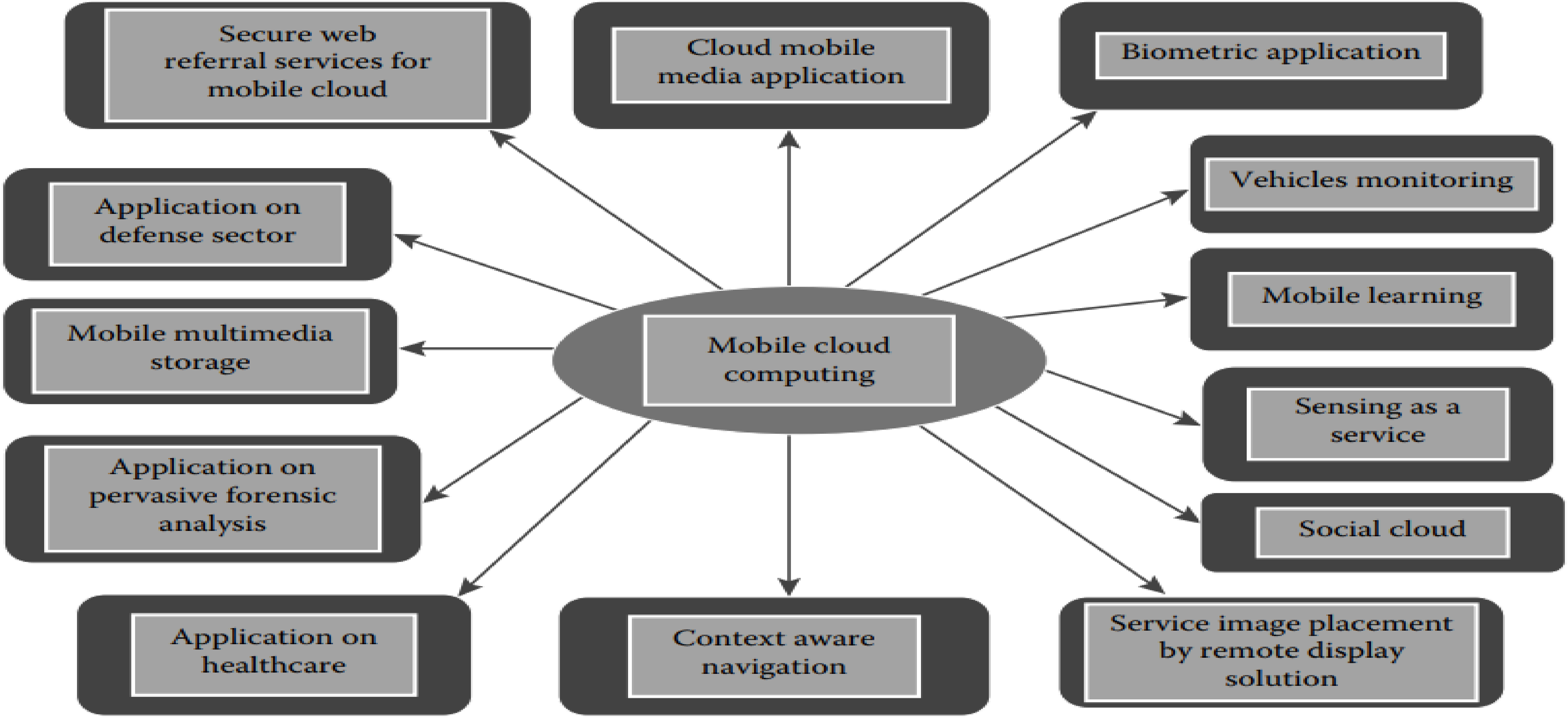
- Recent implementations of **proxy servers** in consumer products, such as **Amazon's Silk** or Opera Software's Mobile browser implementations, have successfully demonstrated the possibility of power savings on mobile devices by modifying content, typically for web browsing scenarios. Proxy-based approaches intercept connection requests and forward these request to the destination (or another proxy). Optimization is typically performed at the proxy level and has to overcome only small overheads with good potentials
- We illustrate the placement of this middleware or proxy service that would enable seamless communications as well as a potentially transparent operation in Figure 8. As illustrated, the middleware acts as intermediary between locally cooperating devices, such as those belonging to the user or nearby others, as well as cloud-based resources accessed through, for example, the cellular connection.

5.3.3 Software and Middleware

Figure 8 Example of the middleware/proxy service placement in the overall communications of a mobile device in the context of mobile clouds



Application of Mobile Cloud Computing



2.4 Network Coding

- Cellular communication architectures are still dominated by point-to-point communication links with centralized management.
- **Mobile clouds** will break with this design paradigm by **relying on distributed functionalities.** For Example, mobile cloud is able to retrieve the content from multiple sources at the same time and, potentially, over multiple air interfaces.
- Due to these radical changes, the underlying communication technology, as well as the policies, will also change.

2.4 Network Coding

- **Some of the fundamental challenges of using multiple sources/ interfaces include:**

1) The need to coordinate what data packets should be transmitted from each source and/or air interface, which requires a large signal overhead.
2) The fact that performance will depend strongly on changing conditions of these sources/interfaces.

- **To break free from these issues, mobile clouds can use network coding.**

2.4 Network Coding

- Network coding breaks with the store and forward paradigm of current networks, where any node in a packet-switched network receives, stores, and forwards packets without modifying their content, and substitutes it with a new paradigm: compute and forward. In this new paradigm, packets coming into a node in the network will be stored but packets going out will be generated as combinations of packets already stored in the node's buffer.

2.4 Network Coding

- This means that an intermediate node in the network can operate on the contents of the incoming data and it allows the destinations to focus on receiving enough combinations to recover the original data.
- This means that coordination between multiple sources/interfaces is relaxed as each source/interface can convey different linear combinations to the end receivers.
- This also allows or more robust mechanisms for dealing with system dynamics as recovery of the data no longer depends on a specific packet being delayed or an interface becoming disconnected, but on receiving enough of it.

2.4 Network Coding

- On the other hand, network coding fundamentally changes resource management in the network.
- Network coding breaks with this assumption and sends out (linear) combinations of the received packets allowing a node to send less, the same, or more than the incoming rate depending on network conditions and topology.
- Its not limited to end-to-end communications and is a viable solution for mobile clouds.
- Network coding operations, such as encoding, recoding, and decoding, can be performed in a variety of mobile devices at very high speeds.

2.4 Network Coding

- The capacity of multicast transmission could be achieved by using network coding for an arbitrary network topology. In fact, linear network coding is sufficient to achieve capacity for multicast flows.

- Random linear network coding (RLNC) showed that allowing each intermediate node to choose random coefficients to create linear combinations of incoming packets is a simple, distributed, and asymptotically optimal approach

2.4 Network Coding

- In Figure 9, a base station conveys the same information to three mobile devices. Instead of using unicast communication for each device, the base station will seed the original data into mobile device A and B by giving each device 50% of the data.
- The figure represented by the data portion a and b. In order to receive the full information, device A and B will exchange the missing parts via device C, which might or might not be interested in the content.
- Such an approach helps to offload the overlay network while the local exchange among mobile devices helps to reduce the energy consumption for the mobile nodes as well as for the network operator

2.4 Network Coding

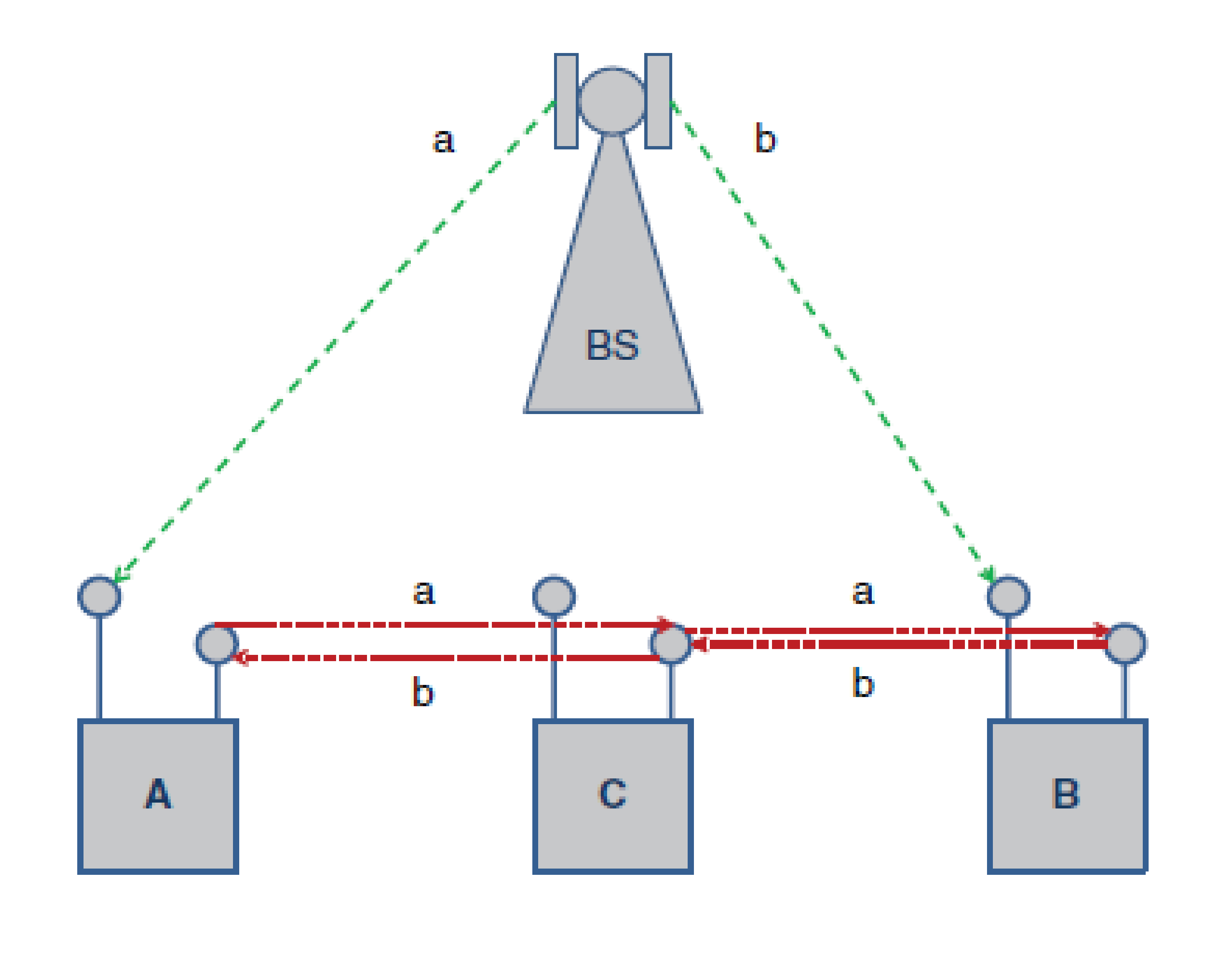


Figure 9: Example for cooperation between devices in a mobile cloud for offloading traffic from the network operators in a multicast session using standard store and forward mechanisms

2.4 Network Coding

- Using store and forward, each packet sent by mobile device A or B will be forwarded by device C to the appropriate device. First, packet a is conveyed from device A to device C, which in turn will forward it to device B in the next time slot. The same happens for packet b, so that a total of four time slots are used to exchange the full information among all devices.

2.4 Network Coding

- Using network coding, mobile device C will perform a linear combination of both packets and broadcast the linear combination to both originating devices A and B at the same time. This reduces the number of transmissions for the full information exchange to three time slots.
- The linear combination in this example is just a simple bit-wise XOR operation of the two packets as shown in Figure 10. Therefore, the broadcasted packet has the same size as packets a or b.

2.4 Network Coding

- On reception at device A and B, the coded packet is decoded by performing another XOR operation between the coded packet and the originally sent packet, that is, a and b in the case of nodes A and B, respectively. <u>This form of network coding is referred to as inter-flow communication.</u>

2.4 Network Coding

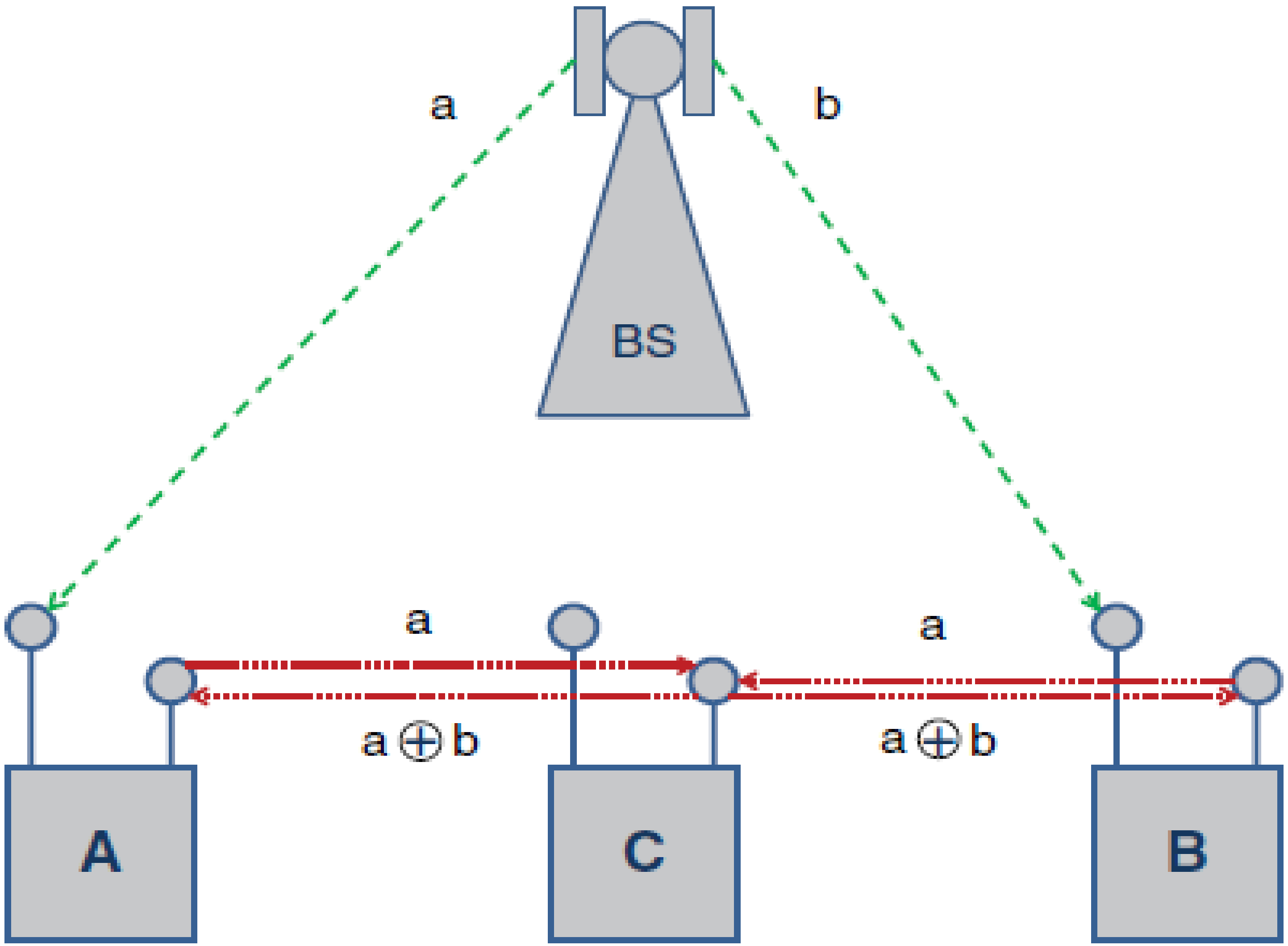


Figure 10: Example for cooperation between devices in a mobile cloud for offloading traffic from the network operators in a multicast session using standard network coding mechanisms.

2.4 Network Coding

- Inter-flow network coding has the advantage of being very simple and therefore imposes low complexity on the platform running it, yet is very effective.
- Inter-flow network coding has the disadvantage of being dependent on the traffic behavior in order to mix flows efficiently.
- In case of slight asymmetry among the streams the throughput gains drop. The reason is the missing coding potential, as not all packets are coded, but just forwarded.

2.4 Network Coding

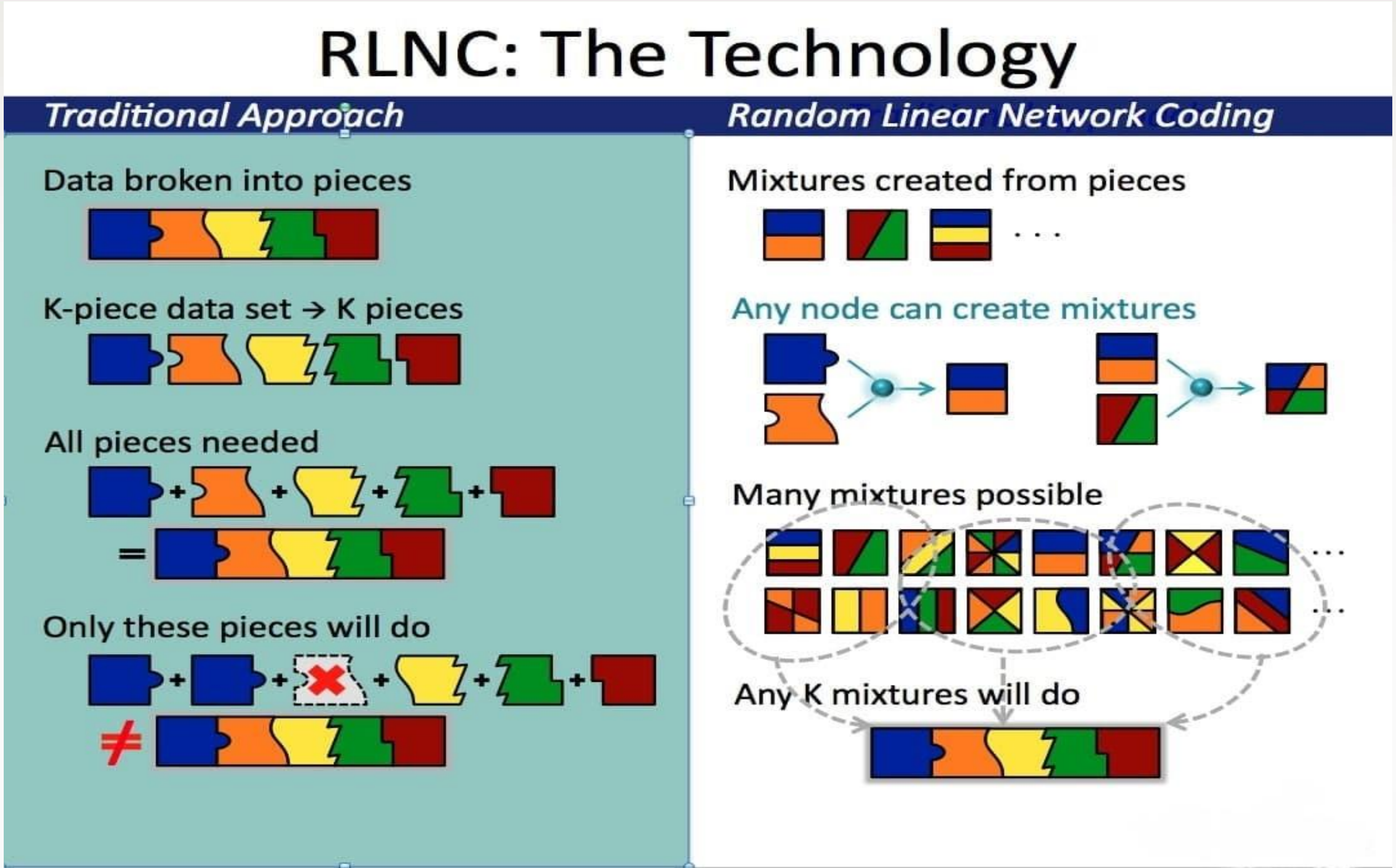
- Therefore the Seeding process from the base station towards the mobile devices is of the utmost importance in creating the highest possible coding gain.

- Another disadvantage of inter-flow network coding is that, in distributed settings, the coding needs to be planned in order to be optimal. This planning results in signaling overhead that is not only reducing the potential gain, but also making the system hard to realize in practice.

2.4 Network Coding

- A more versatile approach called random linear network coding (RLNC).RLNC codes across packets of the same flow, that is, it is an intra-flow network coding approach.
- RLNC codes over groups of data packets called generations. In this sense, a generation of size G consists of G uncoded packets. These uncoded packets are linearly combined with random coefficients α using finite field operations and will lead to coded packets.
- A key property of RLNC is that it can generate an unlimited number of coded packets, that is, it is a rateless code.

2.4 Network Coding



2.4 Network Coding

- RLNC brings forth two major advantages over existing end-to-end codes, namely, the potential to recode packets at intermediate nodes without decoding and the potential to use a sliding window for coding.
- The advantage of this feature over end-to-end erasure-correcting codes is illustrated in Figure 11. We assume node A broadcasts information to four potential relays (R). As there are losses on the first hop, in our toy example some relays would receive the message, others will not.

2.4 Network Coding

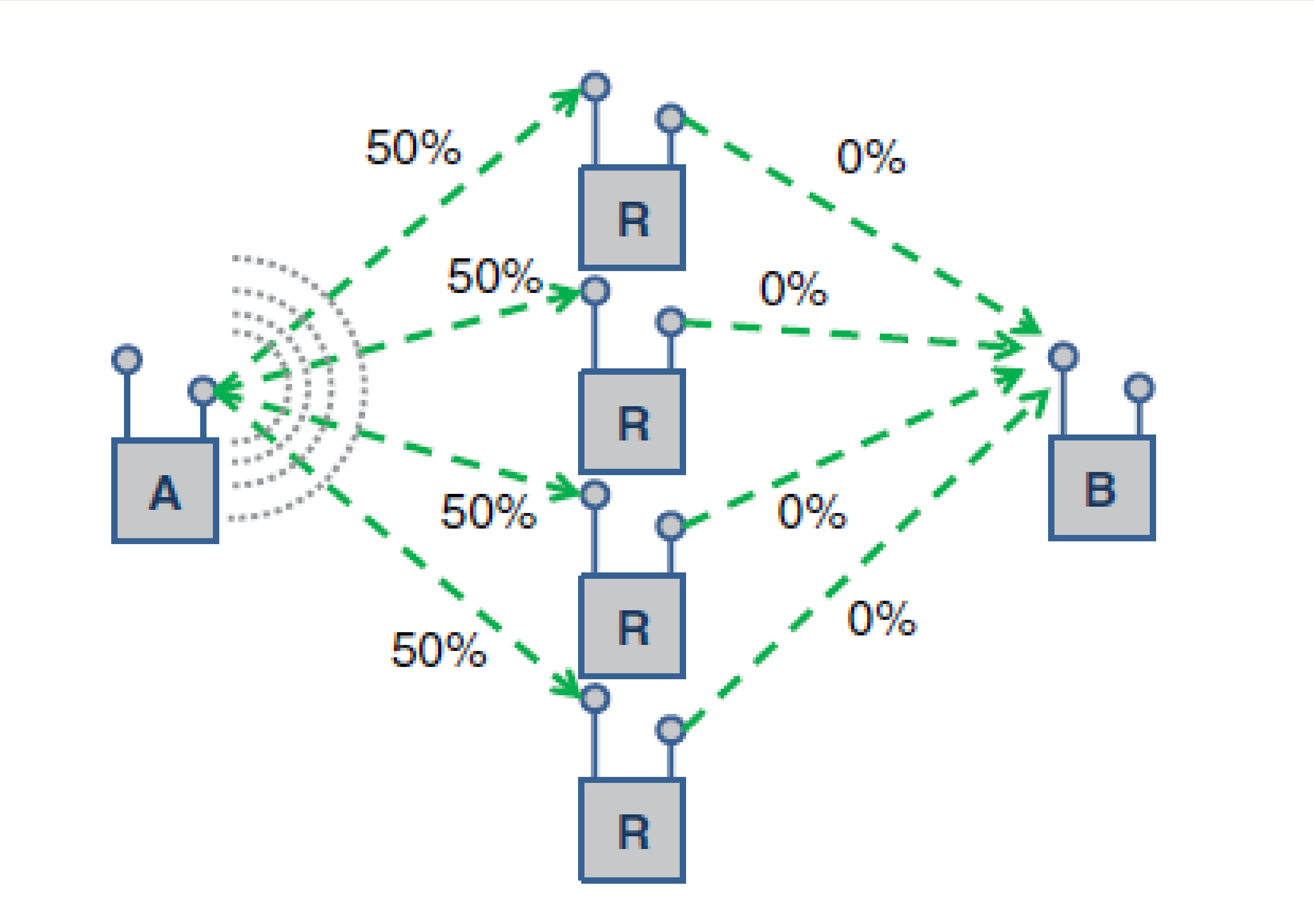


Figure 11 Example of the potential of recoding when multiple relays (R) in a wireless network cooperate to provide a more reliable connection between A and B.

2.4 Network Coding

- In most routing schemes nowadays there would be only one path from node A to node B. As the error probabilities are the same for all possible paths, node A would need to send every packet twice on average to get the packet to the relay as the link error probability is 0.5.
- Assuming G packets that should be sent from A to B, 2G transmissions are needed for the first hop and only G for the second hop as the second link is error free. Exploiting the fact that multiple relays can overhear the transmission, each packet sent out by node A could be received by two relays.

2.4 Network Coding

- If both relays simply forward the packet, the overall number of transmissions will be 3.33G (now 1.33G transmissions on the first hop and 2G on the second hop). The reason is that the relays are forwarding redundant information. However, an optimal scheduler could reduce this to 2.33G.
- As optimal scheduling is hard to achieve, network coding will improve the situation by recoding at each relay and still require 2.33G without any additional cooperation. Now each relay will recode all received coded packets and send linear combinations to node B.

2.4 Network Coding

- Once node B has received G linear combinations, node B will stop the relays to send more information.
- RLNC does not have to wait until the complete generation is available before coding can be started. Every packet that arrives will be coded on-the-fly with already existing packets. Furthermore, packets already seen as part of a combination may be removed from the pool of packets used for encoding.

2.4 Network Coding

- This structure is particularly well suited for streaming applications and protocols that require protection against packet losses in the network while maintaining an in-order delivery of the data.
- This potential has been used to provide reliability to TCP/IP.

THANK YOU