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Green MTC, M2M, Internet of Things

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11.1 Introduction

The capability of having any type of object interconnected and Internet-connected creates an unprecedented access and exchange of information that has been baptized as the Internet of Things (IoT) [1]. With the advancement of integrated technologies, improved batteries, and electronic miniaturization, everyday *things* will be equipped with sensors and microprocessors to collect information around them and execute smart applications. In addition, they will be able to communicate with each other. The IoT has the potential to revolutionize innovations; create new products, services, business; and reshape consumer's behavior. IoT represents a major player for the future of Information and Communications Technologies (ICT).

The development of the IoT must be environment friendly. ICT have shown to be a key contributor to global warming and environmental pollution; it is predicted that the global greenhouse gas (GHG) emissions from ICT will account for 12% of all emissions by 2020 at a growth rate of 6% per year [2]. Therefore, it is mandatory to develop environmentally friendly - or "green" - technologies for the IoT, and ICT in general.

Machine-to-Machine (M2M) communications constitute a fundamental part of the IoT. The term M2M refers to the exchange of data between two or more entities, objects, or machines

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that do not necessarily need human interaction [3]. The envisioned market for such kind of communications is broader than the one traditional human-based communications in terms of number of users and variety of applications. Some forecasts [4] predict figures up to 50 billion machines that will be connecting to communication networks by 2020. This is a very big number compared to the entire world population of around 7 billion people. Therefore, there are some challenges that need to be addressed in order to fully support M2M services in current communication networks [3]. From the technical point of view, M2M communications are substantially different from Human-to-Human (H2H) communications. For example, network operators should provide communication services at low cost in order to face the low Average Revenue Per User (ARPU). Despite the large number of expected M2M connections, most of them will generate very little and infrequent data traffic. Communication networks shall also provide suitable congestion and overload control solutions in order to handle a huge number of simultaneous connections. Features such as low mobility, time-controlled data delivery, group-based policing and addressing, low connection delays, and a wide variety of Quality of Service requirements are among other challenges that need to be addressed. All of them must have the "green" concept embedded. In order to ensure that devices can operate autonomously for years or even decades without human intervention, it is necessary to provide networks with highly efficient communication protocols. This is the main focus of this chapter.

The European Telecommunications Standards Institute (ETSI) created in 2009 a dedicated technical committee to identify key M2M use cases [5–7], understand the service requirements [8], and promote standards for the complete end-to-end M2M functional architecture [9]. Later, in 2012, the global One M2M project was also established by ETSI, with other international standardization bodies, in order to define M2M standards that can accelerate the deployment and success of M2M applications. Figure 11.1 depicts the high-level architecture for M2M according to ETSI, which consists of a Device and Gateway Domain and a Network Domain. The Network Domain consists of the Access Network, the Core Network, and M2M Applications. The Access Network is used to interconnect the two domains, and it could be either a wired or wireless solutions, or a combination of both, to attain the best features of each alternative. Likewise, the Core Network could be of any kind, although it would be desirable

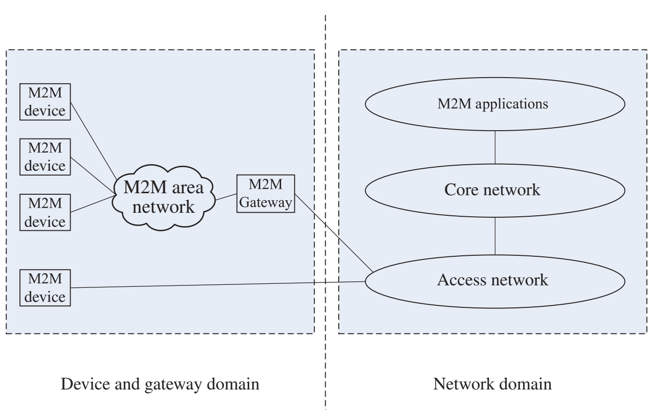

Figure 11.1 High-level architecture for M2M according to ETSI

to ensure that it has Internet Protocol (IP) connectivity. The set of M2M applications, which is referred to as the M2M Application Domain, can be divided into two layers: (i) the lower layer, which consists of the M2M Service Capabilities and constitutes an adaptation layer shared by different upper applications; and (ii) the upper layer, which consists of the M2M Applications and uses the M2M Service Capabilities to access the Core Network. The Device and Gateway Domain is composed of M2M Devices and M2M Gateways. An M2M Gateway can act as the Network Proxy between the devices and the Network Domain (see Figure 11.1), thus forming short-range M2M Area Networks.

In this chapter, the focus is on the Access Network, and in particular, on the pivotal role that cellular networks are deemed to play in the IoT. The benefits of cellular network above any other technology are mainly five:

1. **Ubiquitous coverage**: almost every populated inch of the planet has some level of cellular coverage.
2. **Mobility**: cellular networks enable handover and mobility around the planet.
3. **Infrastructure**: already deployed that can be leveraged to enable new services.
4. **Well-known and accepted technology** by users: there is no need to deploy new networks and infrastructure, and take an effort to make this new technology accepted by users.
5. **Controlled interference**: while other wireless systems operate in license-free bands, cellular networks operate in licensed bands. This provides better control of the interference, which may become a major issue when the number of simultaneous devices is very high.

That being said, and according to the vision of ETSI, cellular networks may be "extended" with capillary networks formed by other short-range technologies such as Low Power Wi-Fi based on the IEEE 802.11 Standard, ZigBee-like networks based on the new amendments of the IEEE 802.15.4, Bluetooth Low Energy (BLE), Radio Frequency Identification (RFID), Near Field Communications (NFC), and many others. Also, wired solutions, such as Ethernet of Power Line Communications (PLC), will very likely have their place in the IoT. However, the ubiquitousness, maturity and mobility capability of cellular networks are increasingly appealing for MTC. For this reason, the focus in this chapter is on the Green Communications that can be attained with current cellular networks. In particular, the focus is on LTE and LTE-Advance (Long-Term Evolution), which is the key technology being developed by the 3rd Generation Partnership Project (3GPP) to facilitate cellular networks. Even though the first releases of LTE did not include any optimization for Machine-Type Communications (MTC) and were mainly focused on achieving very high throughput and low delays, new releases of LTE already include architectural and functional optimizations for M2M applications.

Among other challenges, achieving very high energy efficiency is one of the primary targets. Low energy consumption is crucial for M2M devices because their energy sources are usually scarce, for example, devices rely on batteries or alternative harvesting technologies such as solar panels. In addition, M2M devices may be deployed in high numbers and in remote environments where it would be hard or even impossible to recharge or replace batteries. Not to mention that the fact that the total number of devices will be very high turns the replacement of batteries into a not scalable approach. Therefore, green communications must be embedded into cellular networks, and this is the main focus of this chapter.

The remainder of the chapter is organized as follows. Section 2 discusses different communication techniques that are being explored to improve the energy efficiency of cellular networks and make them suitable for M2M. In Section 3, a number of relevant M2M applications are presented and discussed. Finally, open research issues for green M2M are outlined in Section 4, leaving the final conclusions for Section 5.

11.2 Green M2M Solutions for M2M

The aim of this section is to introduce a number of improvements for wireless networks that have been proposed in the literature to date to reduce the energy consumption in M2M communications.

11.2.1 Discontinuous Reception (DRX)

In today's wireless networks, such as those based on LTE, devices continuously—or very frequently—listen to the downlink control channel to check whether there are pending downlink data transmissions intended for them or there are uplink resources available for transmission. To do so, the radio circuitry of devices is always on, thus consuming energy. While this approach is very efficient to reduce latency in highly demanding applications, it turns very inefficient for bursty packet data traffic patterns with long silent periods. For this reason, the concept of duty-cycling, also referred to as Discontinuous Reception (DRX), can be used for such traffic patterns. A generic DRX scheme is illustrated in Figure 11.2. Time is divided into DRX Cycles, comprising both On and Off Periods. During the Off Period, devices can switch off their receiver circuitries to save energy, and they are said to enter into sleeping state. During the On Period, devices can monitor the downlink control channel. As shown in [10], such operation can significantly improve the energy efficiency in LTE networks.

However, the execution of a DRX scheme inevitably increases latency and communication delay. Note that devices in sleeping state cannot immediately react to traffic changes [11]. For this reason, and in order to meet diverse Quality of Service (QoS) requirements, LTE defines

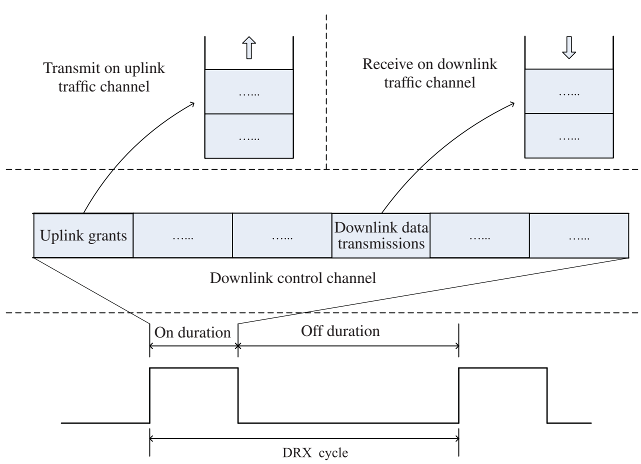

Figure 11.2 Example of DRX cycle

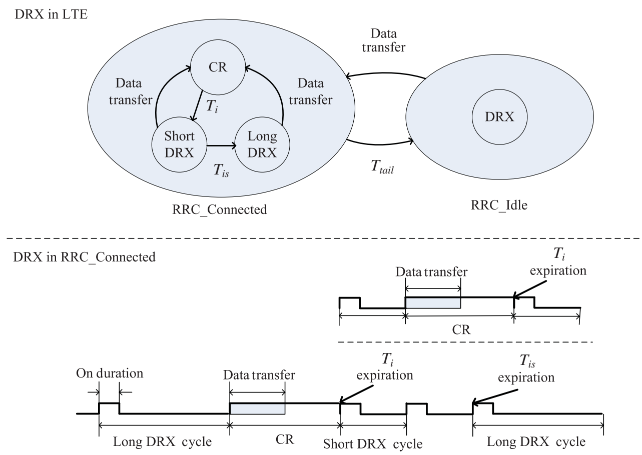

Figure 11.3 DRX mechanism in LTE

the DRX mechanism depicted in Figure 11.3 [12]. The upper part of Figure 11.3 shows the UE (User Equipment) modes in different Radio Resource Control (RRC) states and the transition criteria. There are two RRC states in LTE, RRC_Connected and RRC_Idle. When a UE is in RRC_Idle state, that is, without data to transmit, it operates in DRX mode, alternating on and off periods. However, when the UE needs to transfer data, it makes a transition to RRC_Connected state and operates in Continuous Reception (CR) mode. In this mode, it initiates an inactivity timer (T_i), which is reset every time a new data transfer is originated. When this timer expires, the UE enters into Short DRX mode. From this mode, the UE can go back into the CR mode whenever there is a new data transfer requirement. Whenever the short DRX cycle of duration T_{is} is completed and no data transfer has been conducted, the UE switches to Long DRX mode. Similarly, a UE will switch to CR mode if new data has to be transmitted. If there is no data transmission for the entire RRC_Connected inactivity timer (T_{tail}), the UE will switch back to RRC_Idle state. The lower part of Figure 11.3 shows details of LTE DRX in RRC_Connected state and relationship between the timers used for this DRX operation.

The three DRX modes (DRX in Idle mode and both Short and Long DRX in connected mode) have a similar operation but with different configuration parameters, mainly bound to the duration of the Off Period. The DRX in RRC_Idle state usually has a longer Off Period than those in RRC_Connected state because it is intended for UE with longer inactivity periods. Contrarily, the durations of these periods are shorter in connected state in order to reduce latency. This is vital for some applications. For example, for Voice-over-IP (VoIP), when a transmission starts (i.e. a conversation), periods of on and off activity will be regularly repeated over time.

The durations of On and Off Periods should be configured according to the service traffic pattern and QoS requirements [13]. For example, when the traffic model is stochastic, such as H2H service traffic model, long On and Off Periods will lead to considerable delays, thus degrading the overall user experience. However, some M2M applications are “time controlled” [3]. This means that devices can tolerate long access delays to send or receive data.

In such cases, a DRX scheme becomes very appropriate. For example, Tirronen et al. studied in Ref. [14] the energy consumption of M2M services with deterministic intervals in LTE networks. Their model involved different DRX configurations and concluded that maximizing the DRX Cycle length can achieve significant gains in terms of energy consumption.

All in all, the accurate design of On and Off periods constitutes a very interesting and open area for further research [15, 16].

11.2.2 Adaptive Modulation and Coding (AMC) and Uplink Power Control (UPC)

One of the primary design targets for today's wireless access networks is to achieve ultra-high data rates with large amounts of data to be transmitted in a time period. However, M2M communications often consist of small data transmissions, which means that such high wireless access network capabilities may be not necessary. For example, the Physical Resource Block pair, which is the minimum scheduling physical resource in LTE, can convey up to 712 bits of payload [17]. However, in many M2M applications, for example, sensors monitoring temperature, the amount of data to transmit could be of only a few bytes. This is typically referred to as the Small Data Transmission of M2M applications.

Most of today's wireless technologies provide AMC and UPC mechanisms to cope with the channel variations and adjust the transmission rate to the channel conditions. Indeed, these two techniques can be also used to reduce energy wastage for the transmission of very few bytes of information in M2M applications [18].

For some wireless networks with AMC scheme (such as LTE), the transport block size of a number of physical radio resources is adjustable. This means that the number of payload bits that can be transmitted on a given physical resource changes according to the Modulation and Coding Scheme (MCS) used. The higher the MCS, the more payload bits that can be transmitted per second. However, higher MCS implies that the total energy per bit is lower, and thus more prone to suffer from the errors induced by the wireless channel. In LTE, the AMC balances the data rate and the transmission robustness (probability of correctly decoding) by choosing a proper MCS [19]. From a different perspective, on the premise of receiving bits with a given outage probability, one can compute the capacity of a given channel by selecting the maximum MCS, which ensures the targeted outage probability.

In its turn, the mechanism to define the transmission power in the uplink, the UPC, can also combat channel fluctuations, so that the receiver can always perceive the same Signal to Interference plus Noise Ratio (SINR). In this case, the data rate of the channel can be maintained constant, but the sender needs to consume a variable amount of energy, which depends on the required transmission power. Therefore, if the channel is stable, a higher SINR can be attained by increasing the transmit power. With a higher SNIR, the transmitter can also select a more aggressive MCS to increase the data rate. Therefore, the capacity of a given link can be adjusted by changing the transmit power, in combination with the MCS.

In order to maximize energy efficiency, it is necessary to make sure that the AMC and the UPC are well-designed and optimized for the small data transmissions of M2M applications. For example, conservative MCS could be employed so that the channel capacity could be filled up with small payloads. At the same time, the transmit power could be decreased as the receiver would be able to decode the message with more redundancy bits even with a lower SINR. This approach somehow is counterintuitive to latest proposed mechanisms where the main target is to maximize capacity. For example, the UPC mechanism in LTE includes a parameter $\triangle_{\mathrm{MCS}}$ [17], which is the MCS dependent power offset. The scheduler in LTE can utilize this parameter to inform the devices to reduce their transmit power when using conservative MCS. Therefore, devices can conserve energy when transmitting small M2M packets by using both conservative MCS and low transmit power.

11.2.3 Group-Based Strategies

M2M devices with either similar functions, or located in close geographical positions, communicating with the same gateway or server, can be grouped together. Then, group-based policies can be applied to reduce signaling and improve the energy efficiency.

Generally speaking, it is possible to define two types of MTC groups (or clusters): **static** and **dynamic**.

The devices connected to a common M2M Gateway could become a group, with the M2M Gateway acting as the group leader and relaying messages between the devices and the Network Domain. Considering that the M2M Gateway usually owns stable and unconstrained power supply, such as mains power, it can continuously act as the group leader, thus creating a static cluster.

In contrast, without a fixed M2M gateway, any device could temporary act as the cluster leader [20, 21]. Among other options, the selection of the device could be based on its battery level and the channel state with the corresponding Access Point (e.g., the eNodeB in LTE). In this case, the group members are dynamically assigned based on their connectivity with the group leader [22]. This means that both the group leader and the group members will change during the network operation when the selection metrics vary or the mobility of the network affects connectivity.

Once devices are grouped, either statically or dynamically, various group-based strategies can be applied. This is a non-exhaustive list of some examples that can be used to improve energy efficiency:

- **Relaying**: The group leader relays messages from the devices to the network, thus saving energy of the group members. Normally, the link distance from any group member to the network is larger than the one to the group leader, thus enabling transmission at lower transmission power and with higher reliability.
- **Offloading**: The establishment of short-range networks, such as a Wireless Local Area Network (WLAN) or a Wireless Personal Area Network (WPAN) among group members, can help reduce congestion and signaling overload in the cellular network. When a large number of devices access the network simultaneously, part of the devices will fail access because of congestion and high probability of collision. They will back off for some random time and re-attempt access again till success. This repetition of the access procedure will drain energy from devices. In such case, the use of an M2M Area Network can help reduce the number of simultaneous access requests through the cellular network and help the devices save energy.
- **Complexity reduction**: Complexity and intelligence can be gathered at some devices, thus letting other devices execute extremely simple functions at very low energy consumption. This could be applied, for example, when some devices are operating at critical battery levels

and need to wait for the harvester device to capture more energy. It is worth mentioning that the 3GPP is already working on the application of this approach to the network domain between the core network and the eNodeB [23, 24]. The main idea is to redistribute the work load of one entity to the other entities during off-peak times. For example, when one eNodeB serves very little number of UEs, it can redistribute such UEs to neighbor eNodeBs and enter into sleep mode to save energy. Another example: if one district is covered by several Radio Access Technologies (RAT), it is possible to shut down some of them if the traffic load is very low. In such case, the network shall transfer current users to other RATs (inter-RAT) or the same RAT but different cells (intra-RAT). If a simple low-complexity device is only equipped with a single RAT, it will lose the connection with the network. In such case, the device must rely on the group leader to act as a relay.

- **Data compression**: The M2M Gateway or group leader can perform packet integration and IP compression functions, which will decrease the volume of required data transmission between the Gateway and the Access network and will help improve the energy efficiency. Small packets received by M2M Gateway from all the devices in the group could be integrated into larger packets, which can better utilize the high capacity of the cellular access networks. In such case, IP Header Compression techniques would be necessary to avoid transmitting very long data packets packed with too many control bits.
- **Control signaling reduction**: Similar signaling messages from the devices could be integrated to decrease the control information load [25]. A solution to do so was presented in Ref. [25], where the signaling integration is done at the eNodeB, thus reducing the control load in the core network. These ideas could be applied by the group leader of a cluster in order to reduce the signaling load between the group leader and the eNodeB.

11.2.4 Low-Mobility-Based Optimizations

Some M2M applications feature low (or even no) mobility. In many applications M2M devices will rarely move, or do so in a very particular and known region. Among other examples, this is the case of Automatic Meter Readers (AMRs) or remote sensing devices deployed in specific locations of a warehouse to monitor some physical or environmental condition. In such cases, some of the mobility management procedures designed for traditional H2H communications could be removed, simplified, or optimized for M2M applications in order to reduce congestion and increase energy efficiency.

The low mobility feature may provide two kinds of relatively static information, which can be used to reduce the signaling load: **location** (according to the association to a cell) and **distance** to the serving eNodeB.

First, while in scenarios with high mobility, the network needs to track the position of devices at all time by using the Tracking Area Updates (TAUs) procedure in LTE, in low mobility scenarios, devices may not change the location frequently and the intervals between TAUs could be increased and thus signaling reduced.

Second, in the case of static devices with fixed distances to the serving eNodeB, the Timing Alignment (TA) parameter will be constant, thus avoiding its periodic update for the devices. This can also be used in the Random Access procedure in the following manner: devices can figure out that a Random Access Response (RAR) is intended for them through the TA information included in the RAR. This reduces the collision probability and the associated signaling load for the repeating access [26].

In the case of static devices with a fixed location and constant distance to the serving eNodeB, they may hold relatively stable path loss. Therefore, they can reduce the reporting period of the measured downlink signal strength.

11.2.5 Cooperative Communications

Cooperative communications are known by their capability to improve channel throughput and enhance the energy usage in wireless networks [27]. As it could be expected, their application to M2M is no exception. Cooperative communications exploit the broadcast nature of the wireless channel and are mainly based on one of the two following principles:

1. In the wireless medium, the distance between a transmitter and the receiver determines the path loss, that is, the loss of signal strength with the distance. This effect is typically modeled with an exponential function inversely proportional to such distance, elevated to the power of an exponent, referred to as path-loss exponent, which is generally comprised between 2 and 4 [28].
2. It is possible to achieve spatial diversity [29], also referred to as cooperative diversity. Relay devices in a cooperative link forward messages from source devices, thus providing the receiver with multiple copies of the messages that have been transmitted through independent propagation paths.

Figure 11.4 depicts the three basic cooperative strategies.

The first type of cooperative communication scheme is the Single-Input Single-Output (SISO) Multi-Hop scheme, based on the principle of the path loss and its relationship with the distance. A long distance link between a source and a destination can be split into short distance transmissions, wherein intermediate devices act as relays. By properly arranging the relays between the source and destination, the total energy consumption of cooperative transmissions will be lower than that of the direct transmission [30].

The second cooperative scheme represented in Figure 11.4 is the so-called cooperative relay. The operation of the scheme involves at least three devices: the source, the relay, and the

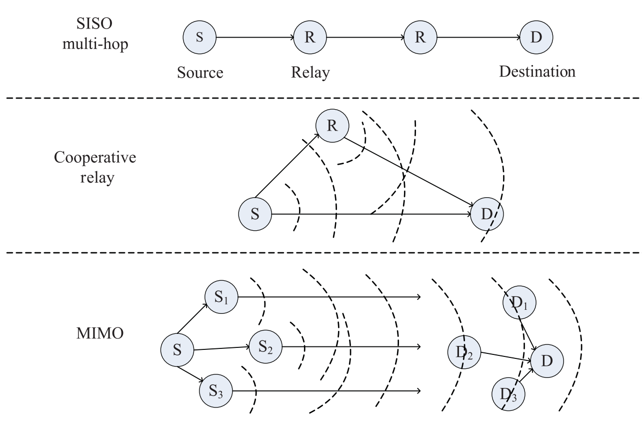

Figure 11.4 Examples of cooperative communications

destination. The transmission operates in a frame-by-frame basis. Each frame consists of two steps. In the first step, the source transmits a data packet to the destination. As the wireless transmission is of broadcast nature, the relay also receives this transmission. In the second step, the relay forwards the data packet to the destination. At last, the destination can combine the two received copies of data applying any combination technique. As the two copies of data are received through two independent wireless channels, the destination can get some spatial diversity gain, which can help decreasing the error rate of data transmissions. This cooperative schemes lets both the source and the relay transmit data with low power while achieving the same required data error rate.

In the case of energy-constrained MTC Devices acting as a source, they may always try to achieve the minimum transmission power by using the relay transmission in all cases. However, under some circumstances, for example, when the channel state between the source and the destination is suitable, the relay may not need to forward data packets for each transmission. In order to save energy, an incremental-relaying scheme such as the one presented in Ref. [31] can be applied. The relay is only active when necessary. In this incremental-relaying scheme, the relay monitors the feedback from the destination to the source after a data packet has been transmitted from the source. When the feedback is a negative acknowledgement (NACK), then the relay forwards the message to the destination.

The third cooperative scheme represented in Figure 11.4 is the Multiple-Input Multiple-Output (MIMO). This case involves a source and a destination, and multiple relays assisting the transmission (cooperative sources) and the reception (cooperative destinations). In this case, a transmission can be divided into three steps. In the first step, the source S transmits data to the cooperative sources S_x (they can be seen as relays). Then in the second step, all the cooperative sources (S and S_x) encode the same data into Space–Time Bloc Coding (STBC) symbols and transmit simultaneously to all the destinations. In the last step, all the cooperative destinations (D_x) forward the received data to the destination D, where a joint signal combination and data decoding is performed. As the MIMO scheme can achieve the diversity of several copies of the STBC, this mechanism allows the sources to transmit data with lower power compared to a transmission with a single hop. Generally, the cooperative sources (or the destinations) are geographically close to the source (destination) and can be grouped to form a cluster. The transmissions between the cooperative devices of the same cluster can be typically done at very low transmission power, thus leading to low power consumption. If there are no cooperative destinations but just a single destination device, the MIMO scheme is actually reduced to the Multiple-Input-Single-Output (MISO) scheme.

In addition to this schemes, where the cooperation is decided by the source, an amount of reactive cooperative protocols have been also presented wherein the decision to perform cooperation is left to the destination [32, 33]. In these reactive schemes, when the destination is not able to correctly decode a received packet from the source, it asks the cooperative devices in the cluster to provide their received data copies rather than asking the source to retransmit the packet. The destination improves the probability of successful decoding and avoids the long-distance data retransmissions from the source, which may consume more energy, and due to the coherence time of the wireless channel, may fail again with high probability.

The first theoretical analysis of cooperative communication dates back to 1979 with the paper by Cover and El Gamal [34]. In this work, the capacity of the cooperative relay system is computed, for an additive white Gaussian noise (AWGN) channel. Since then, a vast number of contributions related to cooperative communications have emerged. A simple Google search with the terms "cooperative communications" results in more than 40 millions results today (2013), just to give an idea. The current active areas of research include the relay selection, the retransmission strategy (Amplify and Forward, Decode and Forward, Compress and Forward, and all their variations), the transmission technique, the interference management, power control, and also research at higher layer of the protocol stack to handle multiple access at the Medium Access Control (MAC) layer, and to deal with cooperation delays at the transport and application layers.

Cooperative communications have been included in 3GPP's specifications for LTE-Advanced [35]. Through the inclusion of relays, LTE-Advanced provides two kinds of cooperative communication scheme:

- **SISO**: a fixed relay can forward messages between the eNodeB and UEs in order to extend coverage.
- **Cooperative Relay**: a fixed relay works with the eNodeB (or the UE) to achieve cooperative diversity and improve the system performance, which is known as the coordinated multipoint (CoMP) transmission or reception in LTE-Advanced.

These two cooperative approaches can benefit M2M applications to reduce energy. However, still a lot of research needs to be done in this area. In addition, particular attention deserves the possibility of enabling such cooperation between devices, leading to the concept of Device-to-Device communications, which are presented in the next subsection.

11.2.6 Device-to-Device (D2D) Communications

D2D communications allow devices to communicate directly with each other without having to route traffic through the base station. D2D communications include the possibility to use multi-hop routes, wherein some devices must collaborate by acting as relays. D2D communications can be exploited to reduce the transmission energy and extend the lifetime of M2M devices operating with cellular technologies, such as LTE. Figure 11.5 illustrates different forms of D2D communications applied to an LTE network.

In traditional wireless networks, devices communicate with each other by means of a common network infrastructure. The used frequency spectrum can be either licensed (e.g., cellular network) or unlicensed (e.g., WLAN). However, when the infrastructure becomes unavailable, for instance, due to a natural disaster or a power blackout, the devices are unable to communicate. Wireless ad hoc communications would be the solution for such cases; the devices in an ad hoc network communicate with each other directly or by using other devices as relays. Indeed, each device may become a router, which may forward the messages so they can reach its final destination. Even though ad hoc networks have received lots of attention from the scientific community in the past, existing deployments are based on proprietary solutions in short-range technologies, and have never reached the cellular domain. However, things are changing today. D2D communications are emerging as an appealing technology to create a revolution in cellular communications by providing very energy-efficient communications and a simple way of offloading core cellular links, thus establishing the ideal framework to deploy the IoT.

D2D communications that work without any network infrastructure can be referred to as non-network-assisted D2D schemes. The air interface can use either the licensed spectrum

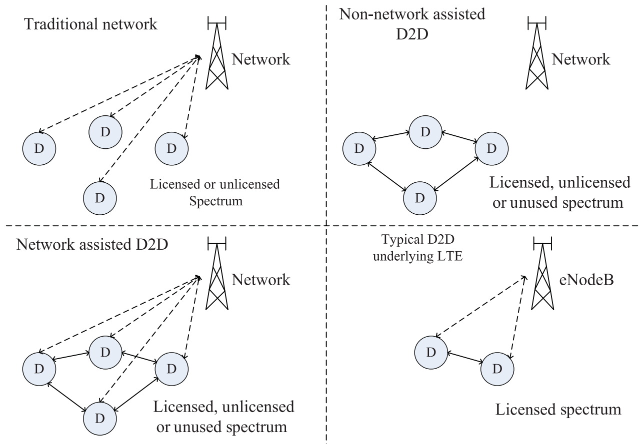

Figure 11.5 Four types of D2D communications

or the unlicensed spectrum. At the same time, some ad hoc networks with cognitive techniques exploit use the unused spectrum to improve the usage of the licensed bands. In contrast, network-assisted D2D communications work with the support of the network infrastructure. In general, the infrastructure may store some information about the ad hoc network and its devices (e.g., location and temporary network topology). By exchanging control information with the devices, the infrastructure helps establish, maintain, and terminate D2D transmissions more efficiently. More importantly, the infrastructure can help the devices establish different cooperative strategies as the ones described in Section 11.2.5), which can help the devices save energy.

In addition, D2D communications may act as an underlay for cellular networks (e.g., LTE as depicted in Figure 11.5) and this scheme has attracted a lot of attention from the scientific community. In such case, when the cellular network finds that the conditions to establish a D2D link are met, it will help the devices involved to establish the direct D2D link and the traffic between the devices will be offloaded from the one being served by the eNodeB. D2D as an underlay to cellular networks may hold several gains [36]; the first one is the **proximity gain**, where the proximity of devices helps reduce the energy consumption, and achieve both high data throughput and low communication delays. The second gain is the **hop gain**, because D2D communications only use one hop compared to traditional cellular communications where two hops (uplink and downlink) are needed, thus reducing latency and complexity, and improving spectrum efficiency at least in a factor of two. In addition, a D2D link saves energy on the eNodeB side as well. The third gain is the **frequency reuse gain**, where the spectrum for cellular network can be reused by D2D communications. In this case, efficient and dynamic **interference management** becomes fundamental piece to make D2D fully beneficial. Finally, **coverage extension** can be also facilitated by enabling the direct communication between devices.

The 3GPP is considering the inclusion of D2D communications as part of the evolution of LTE [37]. In particular, the technique is referred to as Proximity Services (ProSe), and there are two main areas of application:

- To improve the cellular network performance through network offloading, direct proximity transmission, and extended coverage.

- To deploy national security and public safety services on some allocated frequency bands when the cellular network is not available.

11.3 Green M2M Applications

M2M communications are the key cornerstone for realizing the IoT. A lot of innovative applications of IoT based on M2M can help achieve the green world with less greenhouse emissions [2]. This section introduces key applications that will enormously benefit from M2M communications:

- Automotive applications.
- Smart Metering for utility services.
- Smart Grids for electricity distribution networks.
- Smart Cities for sustainable and efficient use of resources in urban areas.

Even though other applications such as building automation, industrial automation, logistics, and remote e-Health, among many others, will also play an important role in the IoT, the focus in this chapter is on the four applications listed before.

11.3.1 Automotive Applications

Vehicles with embedded communication capabilities, for example, WLAN interface or SIM-enabled, can be interconnected to perform a variety of automotive applications that include automatic drive, improved safety, insurance or road pricing, emergency assistance, fleet management, electric car charging management, traffic optimization, or parking services, among many others. [6]. Figure 11.6 shows a simple network topology where M2M devices embedded in the vehicles report real-time location information to a data center. The data center will grasp the traffic information after analyzing all such vehicles location information together with other factors such as weather, accidents, an so on. The data center may broadcast

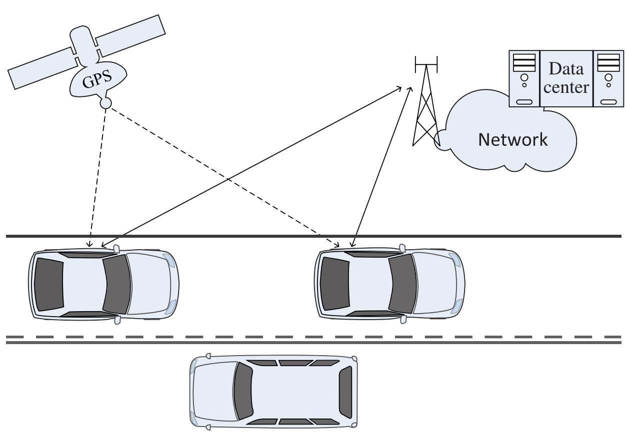

Figure 11.6 Example of automotive applications

a traffic congestion warning to the corresponding vehicles, so they can select other routes to avoid sinking into the traffic jam. In addition, vehicles can send route plan requirements to the data center, so that the data center can plan the optimized route based on the traffic information. Fluent traffic and optimized routes can help to save fuel and mitigate greenhouse gas emissions.

11.3.2 Smart Metering (Automatic Meter Reading)

Smart Metering, or Automatic Meter Reading (AMR), will facilitate the reading of instantaneous utility consumption (water, gas, electricity) by both costumers and utilities. This will benefit both users, who will be able to understand their consumption and adapt their demand to the price of the resource at each time of the day, and for the utility, who will be able to better manage their generation, distribution, and storage plants [7]. A better usage of the resources will have a benefit for both users and utilities, and will help reduce the dependency on natural resources.

Figure 11.7 depicts an example of a Smart Metering application, where the smart meters are connected to a data center through an M2M gateway. The data center can remotely read the meters, and pricing information and estimated bills can be sent to the in-home display for customers. Then, customers can "learn" how and when to use energy to reduce the total cost. In addition, Smart Metering can help suppliers collect customer usage information in order to provide better services. For the distributors, the Smart Metering helps them monitor and manage their networks effectively.

11.3.3 Smart Grids

A Smart Grid is an electricity supply network that relies on ICT to efficiently detect and react to changes in usage. This network is an economically efficient and sustainable power system

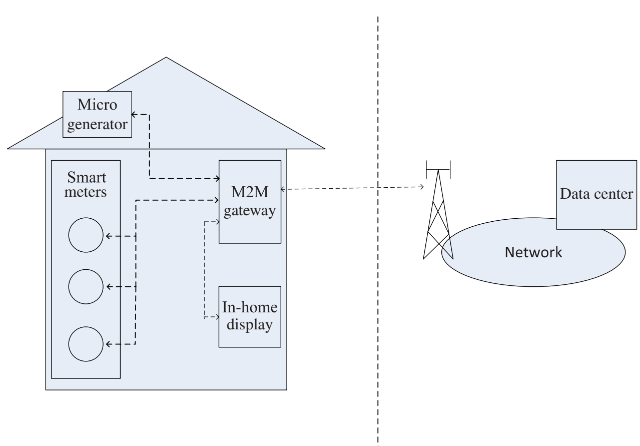

Figure 11.7 Example of smart metering application

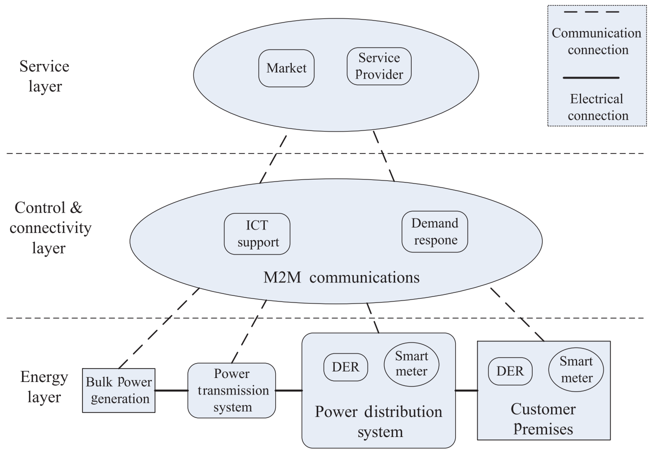

Figure 11.8 Example of smart grid architecture

with low losses and high safety, which also provides high levels of quality and security of supply [5]. In order to connect all users among them, Smart Grids need a telecommunication infrastructure with large-scale coverage, high quality, and security. In order to supply electricity efficiently, Smart Grids need to collect different types of information from the generators, the transmission system, the distributors, and the customers, which will rely on a great number of smart meters and sensors. The telecommunication infrastructure should support M2M communications efficiently.

Figure 11.8 describes the basic conceptual architecture of a Smart Grid, which can be divided into 3 main layers:

- The **energy layer** includes the energy generators, transmission systems, distribution systems, and the customer premises, where the Distributed Energy Resources (DERs) are local energy generators and storages. Between them, the electrical connections create the energy network.
- The **control connectivity** layer consists of the ICT and Demand Response (DR) entities, which are connected with all energy entities via M2M communications. The ICT entity collects, analyzes, and processes the information from all the energy entities. It also commits the strategies and commands from the market and service provider in the service layer.
- The **service** layer consists of the Market and Service Provider entities.

The DR entity is the key for smart grids to reduce the greenhouse gas emissions with the following functions:

- Reduce the power peak and peak time by properly arranging the power demands over time. DR provides mechanisms (such as dynamic prices) to encourage customers to shift their demand from the peak time to periods of lower power demands. As electrical grids are mainly sized by the peak demands, less peak demands decrease the total capital expenditure and operation expenditure of electrical grids. This will also lead to reduced need for energy

storage and also reduced energy wastage (generation of energy that can be neither stored nor consumed).
- Balancing the power demand and supply in the network by dynamically optimizing the power flows, this will decrease the transmission and distribution losses. Through properly planning and dynamically adjusting the routes of power flows in electrical grids, the transmissions between the power supplies and demands can be reduced.

After the Obama's National Broadband Plan released in 2010, the push for Smart Grids has become very intense. Utilities all over the globe are trying to deploy such smart grid concept, and the inclusion of microgrids and the electric vehicle (EV) will create a shift in the mentality on how we generate and consume energy. In Europe, the Horizon 2020 program, funding research and development activities in Europe and also with worldwide collaboration, will give substantial support to the development of the Smart Grid.

11.3.4 Smart Cities

Today, more than half of the world population lives in cities. What is worse, it is predicted that this percentage will be about 70% by the middle of this century [38]. Therefore, cities are dominating the human society development and it is generally accepted that the prosperity of cities does not depend on their economic success. Actually, UN-Habitat believes that the prosperity of cites should include five dimensions [38]:

- Productivity.
- Urban Infrastructure.
- Quality of Life.
- Equity.
- Environmental Sustainability.

To some extent, the concept of smart city can represent this evaluation system of city prosperity, even though there is no consensus of its definition so far. Caragliu *et al*. in Ref. [39] believe a city to be smart when there is investment in human and social capital, transport, and ICT communication infrastructure; such investment fuels sustainable economic growth and improves the quality of life, with a wise management of natural resources, through participatory governance. As we can see, one main object of smart cities is the "green" city, which means that urban areas are able to manage appropriately the natural resources and modern infrastructures to improve the energy efficiency and reduce pollution, thereby achieving the sustainable environment. The modern communication infrastructure (especially the MTC or M2M communications) not only enables the other infrastructure wiser and greener, but also provides tools to monitor the environment and collect information for a more efficient management. From the technology point of view, M2M communications provide the interconnections between the information sources (such as monitors for electricity, natural gas and pollution), data centers (which store and analyze various data), and decision makers (which make decision according to the conclusions and results from the data centers.). Some key M2M applications for smart cities are as follows:

- Smart Parking provides the information of the adjacent parking space for drivers through monitoring the space usage. Then, people can save the time and gas to park, besides improving their well-being.

- Smart Litter Bins provide the bin usage information to the city councils. Then, they can arrange the optimal times and routes for garbage trucks, which can avoid the waste of excess garbage picking and can collect the garbage in time preventing the overfilling of bins.
- Pollution Monitoring utilizes sensors deployed widely in the cities to collect real-time environment information. People can produce immediate reactions for the environment destruction. The long-term information can be the basis for the authorities to make the city development strategies and policies considering the environment sustainability.

The number of possible applications is enormous, and the smart city concept is getting more and more popular around cities. As for the other applications outlined in this section, the opportunities are there, and the challenges as well. In order to make smart grids, smart automation, smart cities, and whatever smart application based on M2M communications a reality, still some political, societal, market, and technical challenges need to be faced. Even though many challenges have been already identified along this chapter, additional open challenges are summarized in the next section.

11.4 Open Research Topics

While the challenge of energy-efficient M2M communications has been extensively studied in the scientific community, there are many research topics still to be solved. Among others, it is possible to identify the following:

Optimization of Existing Wireless Networks for M2M: current communication systems have been designed to satisfy human-based applications demanding high capacity. However, the requirements of M2M applications are completely different, and thus adaptation and optimization of existing wireless networks are necessary. In addition, such an adaptation would be an economic, reliable, and fast solution to achieve efficient M2M communications without requiring to deploy new dedicated networks for M2M traffic. This adaptation and optimization must be done ensuring ultra-high energy efficiency so that real smart and autonomous applications can become feasible.

Cooperative Schemes for M2M with Network Coding: As discussed in Section 11.2.5, cooperative communications, embedding network coding techniques, are a promising technique to achieve ultra-high energy efficiency for M2M. M2M requires simplicity and low cost, thus the inclusion of network coding techniques—which are capable of distributing the complexity among cooperative relays—may be an interesting research path towards feasible M2M deployments. How to assign partners for this cooperation is still an important question, especially, when energy-constrained devices and non-energy-constrained UEs coexist in the same network. The two kinds of devices have different costs for energy consumption and different requirements for data rates. Designing algorithms to form cooperative groups ensuring that they will contain the two kinds of partners will help improve system performance. Furthermore, effective incentives must be designed for non-energy constrained devices assisting energy constrained devices. The reward for the relay may be higher data rate chances, for instance. Such kind of incentive should consider the potential selfish behavior, which may lead to the wrong cooperative partner assignment and lower system performance. Security is a key research topic in this area.

D2D Schemes for M2M: Enabling short-range communications using the main cellular air interface will leverage energy efficiency and enable scalable network deployments. To achieve all the benefits discussed in the previous section, it is still necessary to conduct research in a new technique that is in an exploration and maturation phase. Radio resource allocation (scheduling), power control, and interference management are key areas that need to be developed to enable D2D communications and thus facilitate the use of cellular networks for the efficient and scalable coexistence of humans and machines.

11.5 Conclusions

Even though there is no common agreement on the magnitude of the number of connected devices that emerge in the coming years, there is no doubt that the IoT is around the corner. Millions or billions of things will be equipped with sensor, microprocessors, and radio frequency transceivers to sense the environment, analyze the gathered data, communicate with each other, and enable smart applications. Smart driving, Smart cities, Smart Grids, and Smart Metering are just some key examples of emerging applications that will create a revolution in the very near future. However, still many challenges need to be faced before these applications can become commodities. One of them is ensuring almost zero-power operation of communications. The fact that these devices will be too many and possibly not reachable once deployed claims for autonomous operation. Even though it is improving, today's communication technologies are still power hungry, and this need to be changed. The design of green technologies that can enable long-lasting autonomous operation of communication devices constitutes one of the main challenges to be faced. In this chapter, we have discussed how cellular networks can become key players in providing the IoT with the requested connectivity. Of course, these networks will be extended and complemented with other short-range technologies, but cellular networks have inherent benefits that must be exploited. Even though emerging cellular standards (LTE-Advance) are very flexible and powerful, still optimization for M2M is necessary. DRX (duty-cycling), cooperative communications, and D2D communications have been identified as promising techniques to tailor the operation of cellular networks to the needs of M2M communications. The IoT is just around the corner and technology must be ready to face this new challenge; green communications are key to facilitate real smart applications.

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References

[1] International Telecommunication Union "ITU Internet Reports 2005: The Internet of Things; Executive Summary," November 2005.

[2] Smart 2020 "Smart 2020, Enabling the low-carbon economy in the information age," The Climate Group, London, June 2008, www.smart2020.org. [Accessed 10 January 2015].

[3] 3GPP TS 22.368, "Service requirements for Machine-Type Communications (MTC)," Stage 1, (Release 12), 2014.

[4] N. Lomas, "Online Gizmos Could Top 50 Billion in 2020," 29 June 2009, http://www.businessweek.com/globalbiz/content/jun2009/gb20090629/_492027.htm. [Accessed 10 January 2015].
[5] ETSI TS 102 935, "Machine-to-Machine communications (M2M); Applicability of M2M architecture to Smart Grid Networks; Impact of Smart Grids on M2M platform," V2.1.1, September 2012.
[6] ETSI TS 102 898, "Machine-to-Machine communications (M2M) M2M Use cases of Automotive Applications in M2M capable networks," V1.1.1, April 2013.
[7] ETSI TS 102 691, "Machine-to-Machine communications (M2M); Smart Metering Use Cases," V1.1.1, May 2010.
[8] ETSI TS 102 689, "Machine-to-Machine communications (M2M); M2M service requirements," V1.1.1, October 2010.
[9] ETSI TS 102 690, "Machine-to-Machine communications (M2M); Functional architecture," V1.1.1, November 2011.
[10] C. S. Bontu and E. Illidge, "DRX mechanism for power saving in LTE," IEEE Commun. Mag., vol. 47, no. 6, pp. 48–55, 2009.
[11] K. Zhou, N. Navid, and S. Thrasyvoulos, "LTE/LTE-A discontinuous reception modeling for machine type communications," IEEE Wireless Commun. Lett., vol. 2, no. 1, pp. 102–105, 2013.
[12] 3GPP TS 36.321, "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Medium Access Control (MAC) protocol specification," 2012, (Release 11).
[13] Y. Yu and K. Feng, "Traffic-based DRX cycles adjustment scheme for 3GPP LTE systems," in IEEE 75th Vehicular Technology Conference (VTC Spring), Yokohama, May 2012.
[14] T. Tirronen, A. Larmo, J. Sachs, and B. Lindoff, "Reducing energy consumption of LTE devices for machine-to-machine communication," in IEEE Globecom Workshops, pp. 1650–1656, Anaheim, CA, December 2012.
[15] S. Jin and D. Qiao, "Numerical analysis of the power saving in 3GPP LTE advanced wireless networks," IEEE Trans. Veh. Technol., vol. 61, no. 4, pp. 1779–1785, 2012.
[16] J. Liang, J. Chen, H. Cheng, and Y. Tseng, "An energy-efficient sleep scheduling with QoS consideration in 3GPP LTE-advanced networks for internet of things," IEEE J. Emerging Sel. Top. Circuits Syst., vol. 3, no. 1, pp. 13–22–, 2013.
[17] 3GPP TS 36.213, "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures," 2012, (Release 11).
[18] K. Wang, J. Alonso-Zarate, and M. Dohler, "Energy-Efficiency of LTE for Small Data Machine-to-Machine Communications," IEEE ICC 2013, June 2013.
[19] 3GPP TS 36.211, "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Physical Channels and Modulation," 2012, (Release 11).
[20] J. Alonso-Zarate, E. Kartsakli, L. Alonso, and Ch. Verikoukis, "Performance analysis of a cluster-based MAC protocol for wireless Ad Hoc networks," EURASIP J. Wireless Commun. Networking, vol. 2010, Article ID 625619, p. 16, 2010.
[21] J. Alonso-Zarate, L. Alonso, and Ch. Verikoukis, "Performance analysis of a persistent relay carrier sensing multiple access protocol," IEEE Trans. Wireless Commun., vol. 8, no. 12, pp. 5827–5831, 2009.
[22] R. Y. Kim, "Snoop based group communication scheme in cellular Machine-to-Machine communications," Information and Communication Technology Convergence (ICTC), pp. 380–381, Jeju, November 2010.
[23] 3GPP TS 36.927, "Potential solutions for energy saving for E-UTRAN," (Release 11), 2012.
[24] 3GPP TS 23.866, "Study on System Improvements for Energy Efficiency," (Release 12), 2012.
[25] T. Taleb and A. Kunz, "Machine type communications in 3GPP networks: potential, challenges, and solutions," IEEE Commun. Mag., vol. 50, no. 3, pp. 178–184, 2012.
[26] K. Ko, M. Kim, K. Bae, and D. Sung, "A novel random access for fixed-location machine-to-machine communications in OFDMA based systems," IEEE Commun. Lett., vol. 16, no. 9, pp. 1428–1431, 2012.
[27] T. Nguyen, O. Berder, and O. Sentieys, "Energy-efficient cooperative techniques for infrastructure-to-vehicle communications," IEEE Trans. Intell. Transp. Syst., vol. 12, no. 3, pp. 659–668, 2011.
[28] C. Pu, S. Lim, and P. Ooi, "Measurement arrangement for the estimation of path loss exponent in wireless sensor network," in Computing and Convergence Technology (ICCCT), pp. 807–812, Seoul, December 2012.
[29] H. Chen and M. H. Ahmed, "Performance analysis of cooperative-diversity wireless systems with adaptive modulation and imperfect channel state information," in Wireless Communications and Mobile Computing Conference (IWCMC), pp. 1698–1703, Istanbul, July 2011.

[30] T. Predojev, J. Alonso-Zarate, and M. Dohler, “Energy evaluation of a cooperative and duty-cycled ARQ scheme for machine-to-machine communications with shadowed links,” in Proceedings of the IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC), London, United Kingdom, 2013.

[31] S. S. Ikki and M. H. Ahmed, “Performance analysis of incremental-relaying cooperative-diversity networks over rayleigh fading channels,” IET Commun., vol. 5, no. 3, pp. 337–349, 2011.

[32] G. Botter, J. Alonso-Zarate, L. Alonso, and F. Granelli, “Extending the lifetime of M2M wireless networks through cooperation,” in IEEE ICC 2012, June 2012.

[33] A. Laya, K. Wang, L. Alonso, and J. Alonso-Zarate, “Multi-radio cooperative retransmission scheme for reliable machine-to-machine multicast services,” in Proceedings of the IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC), pp. 1–6, Sydney, NSW, September 2012.

[34] T. M. Cover and A. A. El Gamal, “Capacity theorems for the relay channel,” IEEE Trans. Inf. Theory, vol. 25, no. 5, pp. 572–84, 1979.

[35] 3GPP TS 36.912, “Feasibility study for Further Advancements for E-UTRA (LTE-Advanced),” 2012, (Release 11).

[36] M. Belleschi, G. Fodor, and A. Abrardo, “Performance analysis of a distributed resource allocation scheme for D2D communications,” IEEE GLOBECOM Workshops, pp. 358–362, Houston, TX, December 2011.

[37] 3GPP TR 22.803, “Feasibility study for Proximity Services (ProSe),” (Release 12), 2014.

[38] UN-HABITAT, “State of the World’s Cities: Prosperity of Cities,” 2012/2013.

[39] A. Caragliu, Ch. Bo, and P. Nijkamp, “Smart cities in Europe,” 2009.