

# 12

## Energy Saving Standardisation in Mobile and Wireless Communication Systems

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### 12.1 Introduction

As should have become apparent from the previous chapters, energy saving (ES) has to be considered as a system-wide optimization effort, and for distributed systems like wireless/mobile networks, where many components of potentially different vendors have to cooperate, functioning together in an interoperable way, standardization is essential. In this section, we focus mainly on ES-related efforts of the 3rd Generation Partnership Project (3GPP) and Institute of Electronic and Electrical Engineers (IEEEs) standardization bodies. 3GPP is a worldwide organization defining the most important and successful standard for mobile communication. The brand names of UMTS (also known as “the” 3G technology) and its “Long Term Evolution” (LTE, nowadays taken synonymously for 4G) are well known. They also maintain the specifications of predecessor technologies GSM and GPRS. Besides 3GPP, other complementary organizations among the most noticeable ones, the Next Generation Mobile Network (NGMN) Alliance and GSM Association (GSMA) aim to deliver the mobile operator perspective to other standardization bodies and into the telecommunications industry. Specifically, NGMN Alliance is an operator-driven forum concentrating on mobile broadband technologies and particularly on LTE and its evolution. GSMA is a mobile operator’s interest group, which enables the advancement of mobile technology by coordinating with regulatory bodies, public policies, device and network infrastructure industry.

The IEEE 802.11 and the Wi-Fi Alliance (WFA) are the two standard organizations responsible for the definition of the Wi-Fi technology including ES-related mechanisms and operations. The two organizations work in a complementary way, where the IEEE

802.11 group is technology-oriented with the aim of developing standards, and the WFA is market-oriented and leverages the technical specifications defined by the IEEE 802.11 group in order to create certifications and test plans defined around market segments involving the Wi-Fi technology. Alongside standards bodies that shape ES technologies like 3GPP and IEEE, other standards organizations including the European Telecommunications Standards Institute (ETSI) and the Alliance for Telecommunication Industry Solutions (ATISs) specify measurements procedures and ES metrics for evaluating energy efficiency for telecommunication systems. ETSI introduced the Green Agenda to address ES in several sectors of Information and Communications Technologies (ICTs) including mobile, radio and broadcast, specifying measurements and metrics, which accommodate certain regulations from the European Commission. ATIS is a North American partner of the 3GPP, which created the Green Initiative that focuses on power consumption metrics and standards.

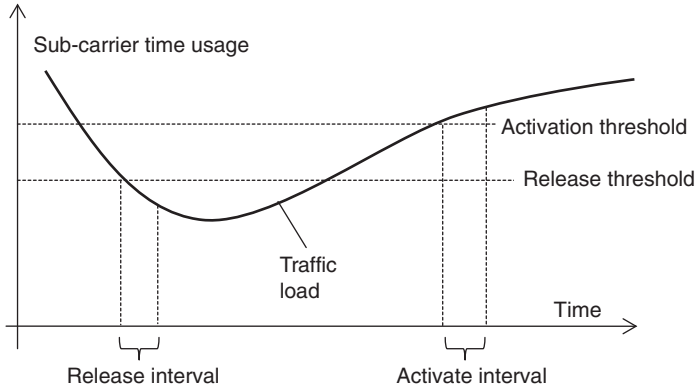
The remaining of this chapter is organized as follows. Initially, an overview of the early NGMN ES activities is provided and then a detailed overview of 3GPP is presented, analysing the main contributions across the different working groups. A summary of ES efforts in GSMA is then presented documented, followed by a brief analysis of the main activities on ETSI and ATIS. Finally, IEEE 802.11 and Wi-Fi Alliance are analysed before deriving the conclusions.

## 12.2 Next Generation Mobile Networks (NGMN)

NGMN launched one of first efforts for addressing ES in mobile networks as a part of the Self-Organizing Network (SON) study, which analysed business requirements focusing on network management for LTE. Such a study opened the horizons for 3GPP to specify technical requirements for SON functions and initiate ES work items, as analysed later in the corresponding 3GPP section. ES SON parameters and requirements are briefly introduced in Ref. [1], with the objective to provide a close match of the operator's offered capacity to the traffic demand, minimizing the energy consumption by powering off certain base station (or evolved Node B (eNB) in 3GPP terminology) components, for example, RF resources and circuits, pilot channels, and so on, or even power-off entire eNBs. The mechanism considered is based on a threshold policy, which activates and releases eNB resources enabling energy efficiency according to traffic load variations or QoS experienced by the end users.

A simple example that elaborates such threshold policy is illustrated in Figure 12.1 showing how the activation and release of resources is performed in relation with traffic load variations. When the network utilization satisfies a predetermined threshold for a sufficient time interval, then the appropriate resource release or activation takes place. Periodic checking, for example, every 15 minutes, or on per flow basis are the two options for examining the shortage or excess of resources.

The Operational Expenditure (OPEX) and network management aspects for enabling ES in LTE, providing a set of best practices is investigated in Ref. [2], assuming network elements can support a standby mode with the potential to be powered on and powered off remotely by a management system, which follows an autonomous capacity-driven ES optimization. A set of recommendations were introduced for network elements and for the element manager considering traffic reporting, neighbour sites updates, dynamic energy policy provision for configuring thresholds and policy rules, and interaction with other SON functions including alarm suppression, resiliency and heterogeneous network issues. As a result, potential standardization objectives were derived for physical layer broadcast channels, performance



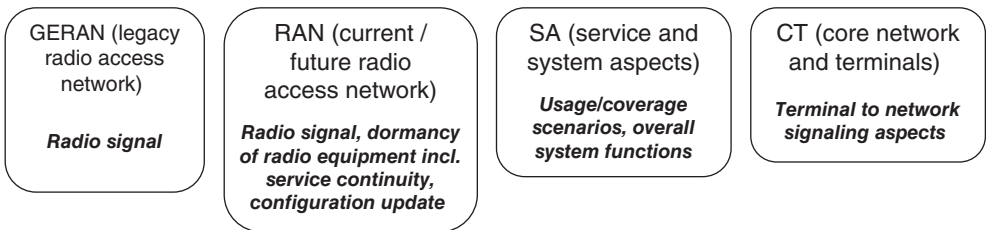
**Figure 12.1** Energy efficiency triggering for releasing and activating resources at the eNB [1]

management reporting in terms of traffic or radio capabilities, cell coverage characteristics and configuration management for controlling network element functions, that is, power on/off, change tilt, control air conditioning units and power amplifier, and so on.

### 12.3 3rd Generation Partnership Project (3GPP)

3GPP is structured in many different work groups, which progress in parallel in a co-ordinated manner focusing on a particular aspect of the mobile network. An overview of the different working groups is depicted in Figure 12.2, highlighting the topics related to ES, which have been investigated so far.

3GPP integrates the work handled by different workgroups by issuing a set of parallel system-wide “releases,” which provide a stable platform for implementation, while allowing the addition of new features in a coordinated manner. Table 12.1 provides an overview of ES-related activities in 3GPP standardization per release by listing the topic/goal, the work group and the documented results. It should be noted that for a comparative view between 3GPP releases, always the (latest) version of the specification/technical report per release should be considered. Technical reports indicated by “TR” are informative documents, which aim to provide use cases and technical content, while specifications represented by “TS” are



**Figure 12.2** 3GPP workgroups involved in energy saving (with the related topics)

**Table 12.1** ES related efforts in 3GPP's standardisation

3GPP release	Topic/goal	Work group	Type	Documentation
9	Inter-eNB ES for E-UTRAN (by cross-eNB signalling)	RAN3	Specification	36.300 [3]
10	OAM scenarios for ES in RAN	SA5	Study	32.826 [4]
	ES management (requirements)	SA5	Specification	32.551 [5]
	ES in NB (UMTS/UTRAN)	RAN1, RAN3	Study	25.927 [6]
	ES in eNB (LTE/E-UTRAN)	RAN3, RAN2	Study	36.927 [7]
11	OAM aspects of inter-RAT ES	SA5	Study	32.834 [8]
	ES impacts on UE to NW signaling	CT1	Study	24.826 [9]
	Additional requirements on inter-RAT ES and probing	SA5	Specification	32.551 [5]
12	System improvements for ES	SA2	Study	23.866 [10]
	UE power Optimization	SA2	Study and specification	23.887 [11]; 23.401 [12]
	Network ES in E-UTRAN	RAN3	Specification	36.300 [3], 36.413 [13], 36.423 [14], 25.413 [15]
	ES Enhancements for E-UTRAN	RAN3	Study	36.887 [16]

normative documents. Typically, a technical report precedes a specification document, which is initiated once consensus is gained after the completion of a corresponding informative technical study.

In 3GPP, the work on ES was initiated mainly from the RAN workgroups and from the network management workgroup SA5. The motivation was based on observations that the permanent operation of the radio part of a radio base station consumes a considerable amount of the overall power [4], even during off-peak hours, where the utilization factor is quite low. Switching off equipment, especially radio parts, is thus a natural goal, but not a trivial task: the service should be guaranteed for the users remaining active with sufficient quality. Such operations were not foreseen in the original design.

### 12.3.1 *Service and System Aspects Work Group 5 (SA5 – Network Management)*

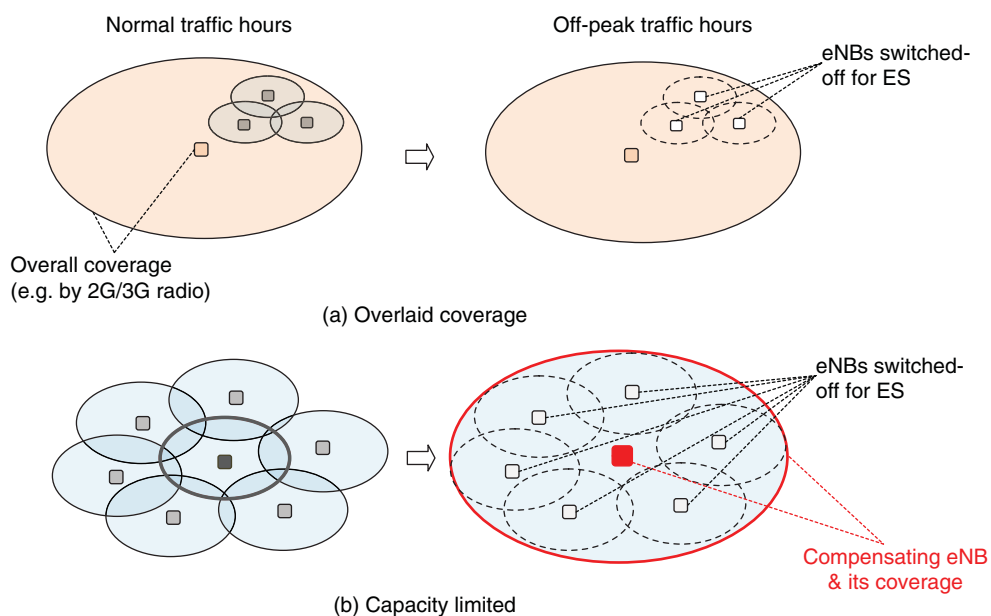
SA5 workgroup introduced ES in 3GPP Release 10 with a study on the following two main use cases, focusing on LTE radio cells and base stations (i.e. eNBs):

- (a) eNB overlaid scenario: Overlapping coverage is provided either by 2G/3G or by LTE eNBs with different carrier frequency bands, as it would be the case in a combination of macro and pico/micro cells within the same area (see Figure 12.3(a)). Sub-variants are defined

- either as carrier restricted, that is, only some carrier frequencies of an eNB are subject to ES, or eNB restricted, that is, the eNB radio part is completely switched off.
- (b) Capacity limited network: Here eNBs are classified into the ones that are subject to be switched off during off-peak periods and into the eNBs that provide coverage compensation when the former are switched off, that is, are in ES state (see Figure 12.3(b)). The focus of this use case is on homogeneous environments, that is, pure LTE, considering base stations with dynamic cell coverage capabilities. At peak times, base stations are assumed to be configured with a smaller coverage area per cell than the potential maximum one for providing increased capacity, while once the traffic is low they may exploit their full coverage for ES purposes allowing neighbouring base station to enter an ES state, that is, be switched off.

Following the initial ES study [4], the workgroup concluded that a clear differentiation regarding whether the ES mechanism is performed within a radio access technology (intra-RAT) or across RATs (inter-RAT) is essential. To address the latter, SA5 performed a detailed study and documented the results in 3GPP TS 32.834 [8]. The different combinations of RATs considered are given in Table 12.2, with the main focus concentrating on combinations 2 and 3. It is worth noting that CDMA2000 is defined by 3GPP2 and thus is not a genuine 3GPP RAT, but from Release 8 onwards it is treated with an especially high degree of integration into the 3GPP core network.

Inter- and intra-RAT ES methods can be performed alternatively or in combination. For instance, in the late evening, first intra-RAT ES for LTE (i.e. for eNBs) could be activated, reducing slightly the offered capacity, then – at night when user activity has dropped further



**Figure 12.3** 3GPP SA5 fundamental ES use cases

**Table 12.2** Combinations of RATs for inter-RAT ES

RAT combination	RAT 1 (providing base coverage)	RAT 2 (target for ES)
1	GSM	UMTS
2	GSM	LTE
3	UMTS	LTE
4	CDMA2000	LTE

to a sufficiently low level – inter-RAT ES based on 3G overall coverage may follow, resulting in a complete switch-off of LTE eNBs. The reverse two-stage process could take place in the morning. The relative priority and optimal sequence of ES activation and deactivation is subject to an operator-defined policy, which typically aims to maximize the global network ES performance without compromising user’s service quality. A crucial point to consider for deploying inter-RAT ES is that some UEs may not (i.e. not yet, or no longer) support a certain RAT, hence switching off a particular RAT may cause service loss for such UEs during the ES period.

The switch-off times of particular cells may in the simplest case be pre-scheduled. In a more advanced deployment, the switching on/off of cells and the modification of radio parameters for adapting cell’s coverage should be dynamically determined and controlled, depending on traffic loads. These network management operations are desired to be autonomous and hence can naturally become a feature of SON (self-optimizing/organizing network) functions. Specific ES policies in terms of cell load thresholds (separately for intra and inter-RAT ES) need to be defined in order to trigger the activation and deactivation of ES in a network element. Additionally, related timers have to be determined, to regulate the ES activation/de-activation triggering based on stable load conditions, that is, when the load has been above/below the respective threshold for long enough.

The ES study also outlined three different alternatives for Energy Saving Management (ESM). All three alternatives rely on network-wide traffic statistics that enable the OAM to determine a stable low load period in order to enable/disable ESM procedures on particular parts of the network, ensuring that ES is profitably applied on network elements, avoiding local load minima and oscillations, that is, switching on/off cells frequently. With centralized ESM, the ES-related algorithms are performed in the (centralized) OAM system, whereas with distributed ESM this occurs at the network element level. In hybrid ESM, the ES-related algorithms are executed in a combined way on both OAM system level and on network element level, or only on network element level with a complementary centralized supervision, for example, for conflict resolution or prioritization using global information on certain network elements.

Obviously, with ES, some state modelling is required for base stations (and, in an aggregated view, also for the network); the two main states for configuration and control are “in ES” and “not in ES”. The latter is equivalent to a conventional situation without introducing ES. For the purpose of coverage/capacity compensation, an additional state “compensating for ES” is needed, which applies only for intra-RAT ES. In ES state, a radio station’s hardware components shall be switched off as long as possible, with the exception during an ES probing procedure (which is elaborated later), in where the radio transmitter is active for a minimum

time. To ensure that eNBs can be switched on again, a minimum of hardware and related software needs to run constantly. A cell in ES state does not provide any service to UEs, so it is normally not “visible” to a UE, except during ES probing.

The procedure of “probing for ES” has been added in Release 11 for supporting further ES optimization. During this procedure, an eNB allows a particular cell to indicate its presence in order to collect UE measurements, but prevents idle mode UEs from camping on the cell and prohibits incoming handovers. In this way, the eNB can use such measurements to determine whether a cell in ES state has enough UEs within its reach to take over a certain amount of load by returning into the conventional “not in ES” state.

### 12.3.2 Radio Access Network Working Groups (RAN 1, RAN 2, RAN 3)

The RAN working groups initiated the first activities regarding ES in Release 9 concentrating on E-UTRAN, assuming network deployments with capacity booster cells, which can be clearly distinguished from the cells providing basic coverage. The rationale was to optimize energy consumption by allowing an eNB to switch off, that is, putting into dormant state, a so-called capacity-booster cell under its control, when its capacity is no longer needed and to reactivate it on demand (see Section 22.4.4 in Ref. [3]). Such a decision may be taken by the eNB based on cell load information and configuration data, or alternatively by the OAM system. The eNB is able to move out active mode UEs by enforcing handovers towards neighbouring cells, before the selected cell becomes dormant and can then inform all neighbouring eNBs by initiating an “eNB Configuration Update” procedure via X2 interface (see Section 8.3.5 in Ref. [14]). These peer eNBs keep the corresponding cell configuration data, that is, neighbour relationship, also during a cell’s dormancy, and they can request the reactivation of a dormant cell via the cell activation procedure when the load increases.

In Release 10, ES problems, considerations and possible solutions were studied more intensively. First, the consumption characteristics of a UTRA base station (NodeB) were analysed in Ref. [6]; not as a surprise, the radio equipment and the base band unit have been found as the main power consumption sources. The following four solutions that address ES considering RAN characteristics have been analysed in Ref. [6]:

- (a) Dormant mode (already utilized in Release 9, see above): this solution concentrates on switching off one or more carrier frequencies with the objective to reduce power or completely shut off a Node B. As long as UEs can still find carrier bands, the existing specifications would guarantee uninterrupted service, for example, by triggering handovers.
- (b) Secondary antenna deactivation (in case of MIMO, usage of multiple antennas for the sake of higher transmission rates): It is obvious that ES is possible if parts of the antenna can be switched off depending on the load. MIMO usage in both terminals and base stations can be controlled fully, so no negative side effects are expected from the deployment of this solution. Effectively, this seems just a selective step back from the energy-hungry MIMO enhancements to a single antenna mode of transmission.
- (c) Power control of common channels: In UMTS, the transmission power of common channels is fixed, configured according to the cell coverage. Hence, common channels are broadcast constantly all the way to the cell edge even when there are no UEs receiving them. Through power control, common channels may dynamically change, for example,

be reduced, ensuring though that all active UEs are in the coverage range excluding UEs in idle mode, which may be out of coverage. As a result, the total power consumption can be reduced. However, such an approach introduces problems with UEs around the cell edge especially in case of mobility or transition from idle to active mode.

- (d) Cell DTX: Concentrates on deactivating the transmitter of the base station periodically, for example, on sub-second level. As the power amplifier consumes a considerable portion of energy, ES can be achieved on the order of the fraction inactivity time in relation to the total period. However, UEs would need to adjust to the DTX cycle; this is not possible in some of their sub-states, that is, in idle mode and not for legacy UEs (i.e. such a solution would create backwards compatibility issues).

Another, parallel study was performed for E-UTRAN in Ref. [7], focusing on the dormant mode for inter-RAT and inter-eNB ES, while for intra-eNB ES, an optimization on radio frame level was analysed. These efforts are further advanced in Release 12, detailed in the corresponding technical report TR 36.887 [16]. The target scenarios include ES in overlaid deployments and the LTE coverage layer scenario, which enables a cell switching off provided that coverage compensation is feasible by neighbour cells. The enhancements in the overlaid scenario are mainly QoS considerations, including the case where different overlaid cells may offer a distinct QoS, and cases where the UE QoS demand is considered when switching on/off particular cells. In the LTE coverage layer scenario, a set of additional goals were introduced to avoid compensation when not necessary, reduce interference and consider UE QoS, alongside specific coverage compensation scenarios including a single compensating eNB and multiple compensating eNBs.

### 12.3.3 Architecture Working Group 2 (SA2)

3GPP SA2 initiated a study on ES documented in TR 23.866 [10], regarding system-level architecture in Release 11 but completed only in early Release 12. The scope of the study was on deployment aspects (primarily in the Packet Switching (PS) domain), including potential system enhancements to support energy efficiency. As such, it was a first step into ES within the mobile core network, despite the fact that its current share of energy consumption is not major; this makes sense by anticipating that an increase of demands for resources in the mobile core network is forecasted over the next years, due to trends like machine-type communication and evolving social applications. In other words, the core network is expected to contribute a considerable share to the overall energy consumption unless the ES of the RAN is coordinated with the core network aligning the energy consumption on a user basis. The following four main deployment scenarios were considered in this study (but these have not yet found their way into normative specifications):

1. Pooled deployment of MMEs: When user plane network entities are deployed more distributed, that is, topologically closer to the RAN, it is possible to optimize the routing and reduce the required transmission resources. In contrast, control plane network entities, that is, MMEs, are deployed in centralized pools in order to take advantage of the pooling effects, which include better scaling and load sharing. Effectively, a drawback of such a pooled deployment is that considerable signalling traffic may occur between eNBs, S-GWs and MMEs. System enhancements to minimize the signalling drawback of the



- pooled MMEs would be required, either enabling the S-GW to handle service requests without always the need of MME or enhance the management of the connected mode by the RAN, but such proposals are still early, on a conceptual basis.
2. Load redistribution during off-peak times: ES-favourable NW node utilization through load redistribution during off-peak times at the EPS assumes that the operator has configured pools of MMEs and/or S-GWs to serve the E-UTRAN. These resource pools are typically dimensioned for peak loads, that is, the number of S-GWs, P-GWs and MMEs is chosen according to the expected maximum number of UEs and their traffic demand. But most of the time, the load in the network is far from the dimensioned peak rate, thus operators can expect significant ES opportunities by setting unnecessary resources/nodes in the core network to an energy conservation mode. The net benefit depends here on the non-linearity of energy consumption with load, since a certain portion of energy is consumed already with zero load.
  3. Network sharing: This is a standard way of reducing the operator's cost by cooperation. In rural areas with lower population density, mobile networks may need to provide coverage but already a minimum configuration could offer more resources than actually needed. Hence, network sharing could help realizing ES as a part of overall base station related CAPEX and OPEX. In urban, more densely populated areas, network sharing could also be performed dynamically, during low traffic hours; in this case, the focus is more on OPEX. Specifically, during peak times, the Public Land Mobile Networks (PLMNs) may use their own capacity and coverage, but at off-peak times, every PLMN may utilize only a low-capacity portion. Hence, network sharing could be used at these low traffic hours to improve energy efficiency by combining traffic of multiple PLMNs providing a lower variance than the traffic of each individual PLMN.
  4. Scheduled communications: This feature aims to enhance inter-RAT ES developed in RAN addressing scenarios wherein devices cannot use another RAT. There may be devices (e.g. for Machine Type Communication (MTC)) that can support a single RAT alone and need to communicate only during regular intervals. The network could determine whether in particular areas there are only such single RAT devices that do not need to communicate constantly, or their communication has a low priority and schedule the activation/de-activation of RATs accordingly, while more mission-critical devices may be assumed to have multi-RAT capabilities.

In Release 12, optimizations for UE power consumption were also studied and documented in TR 23.887 [11] as a part of the mobile network improvements for MTC. Since the number of devices is expected to dramatically increase, their accumulated power consumption has to be taken seriously into consideration, apart from that fact that restrictions in power supply may apply in many cases. For MTC devices, SA2 has analysed the following two solutions:

1. Exploitation of (very) long DRX cycles: In this solution, the maximum DRX cycles in idle mode are extended, permitting the UE to save battery, as waking up and listening for a potential paging message is a major power consumption source. The paging transmission period should also be adjusted according to the extended DRX cycle applied to the UE. Indicating and applying extended DRX may be eNB or UE driven with MME assistance for configuring extended DRX and adapting paging. Hence, support of extended DRX from UE, RAN and core network is essential.

2. Addition of a new power saving state: UEs may support a “power saving state,” a state wherein UEs enter based on a timer after transiting to idle state. During the “power saving state” UEs remain attached, that is, active PDP/PDN connections remain established, but halt cell/RAT/PLMN selection as well as NAS procedures. However, UEs still perform periodic registrations (RAU and TAU) following a timer value, which is provided by the network.

The system-level concrete specification of these ES features can be found in TS 23.401 [12].

#### 12.3.4 *User Equipment: Core Network Signalling Working Group (CT1)*

3GPP's CT1 workgroup has performed studies on the impacts of ES on the signalling between UE and core network as documented in TR 24.826 [9], but note that they have not yet lead to normative specification. The UE to core network signalling relevant here are the ones associated to the idle state, that is, registration signalling, whereas active mode is managed by the RAN. In particular, when a base station is switched off, a UE needs to look for another cell to camp on, that is, perform a handover, by tuning to the corresponding radio frequency band and decoding the relevant broadcast information. If the new cell belongs to a different registration area, a re-registration has to be performed. This effect is less pronounced with intra-RAT ES, because it could potentially only happen at the borders of registration areas, and involve only a fraction of the UE population. However, re-registration could result in massive amounts of signalling with inter-RAT ES, that is, when UEs should change RAT, since it affects the registrations of all UEs in the target area, especially when UEs over a larger part of the network attempt to register at the same time. To avoid such a signalling peak towards the core network nodes, an obvious solution is to randomize the registration access or perform a stepwise activation of ES.

The most recent 3GPP system (since Release 8) supports also interworking with access networks of non-3GPP technology, for example, WLAN; if ES is applied to such access networks, handovers will be triggered for the UEs currently using them, either to the 3GPP RAT acting as coverage umbrella or to other non-3GPP access networks available to the UE. The resulting signalling is effectively an attachment in the target RAT and thus includes registration. Hence, depending on the amount of non-3GPP radio access points entering ES mode at roughly the same time, potentially similar issues, that is, peaks of signalling, can occur. Additionally, as handovers for UEs in non-3GPP access with ongoing data transmissions are now managed based on UE to core network signalling, the service experience may be affected.

#### 12.3.5 *GSM/EDGE Radio Access Network Working Group (GERAN)*

For the legacy radio access GERAN, the activity towards ES solutions so far is limited to a study for intra-BTS ES [17]. The reference configurations for sectorized cells of a BTS and load profiles are analysed based on the ES ETSI model documented in Ref. [18]. The proposed ES solution concentrates on dynamically adjusting power for some time slots on the BCCH carrier. Applying this ES scheme in simulations shows that the service quality decreases slightly, while still satisfying the performance target. The call drop rate also increases modestly, but remains in all cases below the 0.2% target. Unfortunately, no concrete values of power saving gains are yet published.

## 12.4 GSM Association (GSMA)

Since 2010, GSMA provides a Mobile Energy Efficiency Benchmarking service, intended as an aid for mobile network operators to measure and monitor the relative efficiency of their radio access networks. Underperforming networks that waste energy can be detected and potential ESs can be estimated. Meanwhile 35 of MNOs, representing 200 networks and more than half population of mobile subscribers, participate with the benefit that a wealth of data, which has already been collected, can be used for future benchmarking, although in an anonymized form.

In creating a benchmark, which represents a statement of relative performance for a particular type of networks, it is most useful to consider a set of networks with similar base characteristics. The energy efficiency is then tracked over time. Following on the benchmarking, GSMA also promotes an enhanced service for energy optimization since 2011; this is run in collaboration with a partner (vendor or system integrator). Aggregated results are compiled in GSMA's Green Manifesto 2012 [19] in the form of energy consumption per connection and per unit traffic. The Green Manifesto contains energy cost and CO<sub>2</sub> emission figures, including forecasts rates for 2020, while introducing also policy recommendations for governments exploiting the potential of mobile communications to enable reductions in global greenhouse gas emissions.

## 12.5 European Telecommunications Standards Institute (ETSI)

ETSI has been particularly active in developing standards, accommodating European regulations, for improving energy efficiency in the sector of mobile and wireless communications and introduced the Green Agenda as a strategic topic since 2008, which includes the following major categories:

- (a) Definitions and reference models for energy efficiency, energy consumption measurements and Key Performance Indicators (KPIs), methods of measuring energy efficiency.
- (b) Specifications, recommendations and best practice guidelines for energy efficiency.
- (c) Life cycle assessment for telecommunication equipment.
- (d) Environmental considerations for telecommunication equipment and installation, power supplies including alternative power sources.

Among ETSI technical committees, the main ones involved in the field of energy efficiency are the Environmental Engineering (EE), which mainly defines energy efficiency, measurement methods and indicators as well as the Access, Terminals, Transmission and Multiplexing (ATTM) that handles broadband technologies including wireless access radio and mobile networks. The EE technical committee has introduced energy efficiency considering wireless access equipment in TS 102.706 [18], providing the criteria for assessing the power consumption of GSM/EDGE, WCDMA, WiMaX and LTE. This specification primarily models the energy consumption of base stations, including integrated and distributed scenarios, base station sites and for the case of GSM the network-level energy efficiency. Additionally, it introduces power consumption measurement methods to address static and dynamic coverage and capacity measurements.

Extensions of such measurements are introduced in Ref. [20], which provides an analysis based on real network characteristics for GERAN, UTRAN and E-UTRAN. It also specifies as energy efficiency metrics: (i) the successfully transferred data volume per unit time

over consumed power and (ii) the number of users over consumed power considering the perceived QoE. Further guidelines for performing energy measurements are also included, concentrating on area measurements, observation times and QoE estimations. Energy measurements regarding base stations are performed directly using a power meter or via supplying RF power measures to an estimation model. The user QoE is determined considering throughput measurements or via packet inspection; alternatively terminal probing or user reporting could inform the network about the perceived QoE.

Energy efficiency measurements for core network equipment are specified on ES 201.554 [21], considering UMTS and E-UTRAN. The specification defines the notion of power consumption and energy efficiency as well as the metrics that should be considered for MGW, HLR, AUC, EIR, MSC, GGSN, MME, SGW and PGW, while in later revisions the radio access control nodes and IMS core are planned to be added. The conditions and procedures for performing energy measurements are also introduced including the system configuration, KPIs and traffic parameters. The relation of energy efficiency subject to specific KPIs is further studied in Ref. [22] to enable consistent monitoring and network assessment. Such KPIs relate power with bandwidth and transmission distance considering also on-demand or varied services. For wireless access, [22] introduces the Energy Efficiency Factor (EEF) to relate the energy usage with the network capability for achieving a given data rate within a certain coverage area, while it also provides measurement recommendations for a broad range of wireless technologies including Bluetooth, Zigbee, WiFi, WiMaX, fixed wireless links, GSM, GPRS, UMTS and 4G.

ETSI also specified the European Standard EN 301.575 [23] concentrating on measurement methods for energy consumption of Customer Premises Equipment (CPE) and test conditions for end-user broadband equipment, that is, CPE (WLAN), under a series of power states/modes including disconnected mode, off mode, standby, idle state, low power state and on mode, conforming the EU regulation 1275/2008. Life cycle assessment considerations for base stations, network equipment and services are analysed in Ref. [24] taking into account equipment material, production and development, operation and support as well as the end of life treatment phases of a product life cycle. The use of alternative energy solutions in telecommunication installations is documented in [25], considering various alternative energy sources and paradigms to power on network equipment, analysing the life cycle of solar power system and diesel generator battery hybrid solutions for GSM base stations.

## 12.6 Alliance for Telecommunication Industry Solutions (ATIS)

ATIS launched the Green Initiative in 2008 and as a part of it the Exploratory Group on Green (EGG) explored environmental sustainability in wireless networks. Its fundamental contributions regarding energy efficiency concentrates on measurements practices and metrics. Specifically, ATIS has introduced in Ref. [26] the Telecommunications Energy Efficiency Ratio (TEER) metric to measure and report the radio base station energy efficiency. TEER is defined as a ratio of equipment performance to energy consumption with respect to data and voice, that is, it addresses base station throughput per Watt of input power. ATIS has also defined a methodology to determine a RF power efficiency ratio as the radiated RF power to the consumed power taking in account three different test locations, that is, near, middle and cell edge, considering a weighted factor that corresponds to a variable load level for each of the three test locations.

Besides the definition of energy efficiency metrics, [26] specifies methods, processes and system configurations for measuring the energy efficiency of LTE, CDMA, EV-DO, UMTS, GSM and WiMaX, with the intention to compare base stations with the same radio technology. ATIS has also published a study item, that is, not a specification, which captures the industry efforts for providing energy efficiency in wireless networks [27]. In particular, it documents base station and cell site energy efficiency considerations focusing on hardware optimizations, management mechanisms and empowering methods, including alternative power at cell sites. The study also analyses network design considerations regarding topology, access network technology, redundancy and network dimensioning and optimization.

## 12.7 IEEE 802.11/Wi-Fi

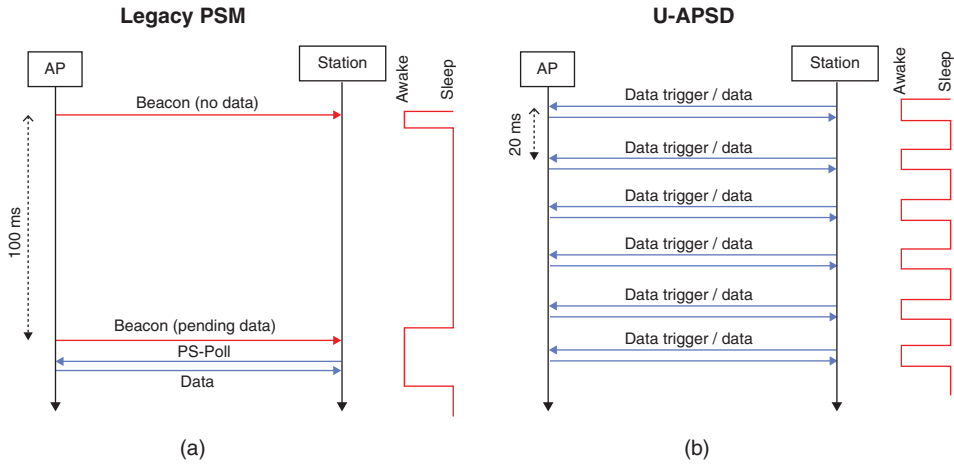
The Wi-Fi industry is currently steered by two major standards organizations that work in a cooperative way, namely: (i) the IEEE 802.11 Working Group, carrying out the task of defining technical specifications and (ii) the Wi-Fi Alliance (WFA), which takes the specifications developed by IEEE 802.11 and defines certification programs. Throughout this section, we refer to the technology developed by IEEE 802.11 and WFA simply as Wi-Fi technology. Unlike 3GPP, these standard organizations do not define the full system architecture but instead limit their efforts to the air interface between the Access Point (AP), that is, corresponding to eNB in 3GPP, and the station, that is, the device capable to use IEEE 802.11, equivalent to UE in 3GPP. Consequently, all ES-related extensions developed for Wi-Fi apply to the air interface only.

Currently, the main efforts to achieve ES in Wi-Fi have been oriented towards extending the battery life of stations, especially for smartphones or other battery handheld devices for which the Wi-Fi interface consumes a significant part of their total energy. For instance, a recent study demonstrates that when the Wi-Fi interface is continuously active, a modern smartphone has a battery lifetime for only 5–10 hours. Therefore, IEEE 802.11 has defined several power saving protocols that mitigate this problem by allowing the device to set its interface in a sleep state when no data needs to be transmitted. These protocols are described in Section 12.7.1.

Wi-Fi APs have traditionally been low-power base stations generally operated by independent entities, for example, private users. As operators start to integrate Wi-Fi hotspots as part of their mobile infrastructure, reducing the energy consumption of APs becomes a significant target. Section 12.7.2 introduces existent functions that can be used for this purpose. Finally, as already mentioned when discussing ES efforts in 3GPP, an emerging trend that requires further energy efficiency enhancements for Wi-Fi radios is MTC, where large number of small and battery-powered sensors/actuators are connected to an AP in order to communicate with a remote MTC server. Improvements to enable MTC, currently under discussion in the IEEE 802.11 working group, are described in Section 12.7.3.

### 12.7.1 Mechanisms to Extend the Station's Battery Life

The baseline 802.11 specification [28] introduces a legacy power save mode that was designed to save power for stations with non-time-sensitive traffic. The 802.11e amendment developed a protocol that was designed to address the needs of stations with QoS requirements, while



**Figure 12.4** Detailed operation of (a) the legacy PSM and (b) the U-APSD protocols

recent amendments like 802.11v [29] contain mechanisms that further improve energy efficiency. In this section, we provide an overview of these mechanisms, highlighting their core ES contributions.

### 12.7.1.1 Legacy Power Save Mode (PSM)

The legacy PSM enables a Wi-Fi station to save energy by informing the AP. Specifically, a Wi-Fi station enters and leaves the PSM, by sending a frame to the AP with the power management bit set to 1 or 0, respectively. Stations in PSM are free to sleep, while the AP buffers any incoming data addressed to them. Consequently, the AP inserts into the Beacon frame, which is usually transmitted every 100 milliseconds, a signalling element that indicates if there is pending data for the stations in PSM. Stations wake up periodically to receive such a Beacon frame, and upon observing a pending data indication, transmit a so-called Power Save Poll (PS-Poll) frame to the AP that triggers the delivery of the pending data from the AP. The operation of legacy PSM is depicted in Figure 12.4(a).

The buffering delay introduced by the AP, which is up to 100 milliseconds, can impact the performance of regular data applications and especially the performance of applications with specific QoS demands. To address such an issue, state-of-the-art approaches like [30] have proposed extensions to the basic protocol that improve the performance of traditional data applications like Web traffic and long file transfers.

### 12.7.1.2 Unscheduled Automatic Power Save Delivery (U-APSD)

As already mentioned, the performance of the legacy PSM is critical, especially with applications having tight QoS requirements. For instance, considering Voice over IP (VoIP), the downlink leg of a conversation for a station operating in legacy PSM could potentially introduce a delay in the Wi-Fi link of up to 100 milliseconds. To reduce such downlink

delay, the U-APSD mechanism allows stations to proactively poll the AP for data, instead of reactively triggering the AP as in legacy PSM. The operation of the U-APSD protocol is depicted in Figure 12.4(b). It should be noted that in U-APSD it is important for the station to have an accurate knowledge of the instants where data frames should arrive at the AP, as polling when no data is available may penalize energy consumption. To address such an issue, estimations of the inter-arrival times between frames in the multimedia stream could prove helpful. A comprehensive comparison and analysis between the legacy PSM and U-APSD is documented in Ref. [31].

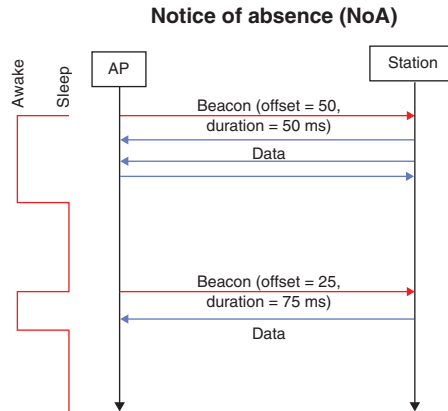
### 12.7.1.3 802.11v Extensions

The 802.11v amendment [29] specifies a toolbox of mechanisms for network management that can be used to further improve energy efficiency. The following ones are the most relevant:

- (a) Proxy Address Resolution Protocol (ARP): The ARP [32] allows a station to discover the MAC address of another station through its IP address. For a station in power saving mode, waking up to respond to ARP requests sent by other stations could prove to be an energy-intensive process. To resolve this issue, the Proxy-ARP allows a station to register its IP address with the AP and let the AP reply to ARP requests on behalf of the station.
- (b) Basic Service Set (BSS) Max Idle Period: The BSS in IEEE 802.11 is defined as a network composed by an AP and a set of associated stations. A common problem in traditional Wi-Fi implementations is that stations are forced to transmit periodic keep-alive messages to the AP in order to avoid being disassociated. The BSS Max Idle Period mechanism can resolve such an energy-inefficient issue, by allowing an AP to advertise towards the associated stations the duration they can sleep without being disconnected, which allows stations to sleep for longer periods.
- (c) Traffic Filtering Service: Allows a station to convey a traffic template to the AP in order to inform it about the traffic that is interested to receive. Traffic addressed to the station that is not matching such a template is simply dropped by the AP. Consequently, a station is waking up only by important traffic, saving energy at all other times.
- (d) Flexible Multicast Service: In legacy PSM, APs deliver all broadcast and multicast traffic only at given periodic times known as Delivery Traffic Indication Message (DTIM) intervals, during which all stations must be awake. To provide ES, 802.11v defined the Flexible Multicast Service that allows stations of a given multicast group to request the AP to transmit data addressed to them only at a multiple time of the DTIM interval, permitting longer sleeping.

### 12.7.2 Reducing the Power Consumption of APs

In traditional Wi-Fi deployments, APs are powered by the electrical grid and their power consumption has not been considered as a significant issue. Therefore, the original 802.11 protocols were designed with the assumption that APs are always operational, that is, awake or powered-on, listening to transmissions coming from the associated stations. However, such an assumption is challenged by the adoption of AP functionality in battery constrained devices,



**Figure 12.5** Detailed operation of the Notice of Absence protocol in Wi-Fi Direct

that is, smartphones, which is already standardized as documented in the Wi-Fi Direct specification. In addition, large enterprise Wi-Fi deployments create a further challenge wherein aggregate power consumption becomes a relevant issue. This section presents emerging solutions to resolve these challenges.

### 12.7.2.1 Wi-Fi Direct: Enabling Battery-Enabled Devices to Act as APs

Wi-Fi Direct (WFD) is a technology specified by the Wi-Fi Alliance in 2010 [33], which aims to allow direct device-to-device connectivity without the presence of a traditional AP. WFD configures one device to emulate a traditional AP and permits other WFD devices to discover and connect to it. Considering ES, WFD needs to specify energy-efficiency operations for devices that act as APs. To address this issue, the WFD specification defined the Notice of Absence (NoA) protocol that allows an AP to specify certain time intervals where stations are not permitted to transmit, and thus the AP can switch off its radio in order to save power. Figure 12.5 depicts the behaviour of the NoA protocol.

The WFD specification does not specify though how an AP needs to configure its awake and sleep intervals, which can affect the performance of the applications run by the devices connected to such an AP. The interested reader is referred to Ref. [34] for a thorough evaluation of the WFD technology.

### 12.7.2.2 Energy Efficient Enterprise Wi-Fi Deployments

Recent Wi-Fi enterprise networks are typically dense deployments with a significant impact on energy consumption. To address energy efficiency, the 802.11v specification introduced the following two mechanisms to reduce the power consumption of APs via network management means:

- (a) **BSS Termination Notification:** This mechanism allows an AP to notify its connected stations that the AP is about to shut down, hence enabling the connected stations to gracefully



transition to a new AP. The APs to be shut down are determined and controlled on-demand by a network management system.

- (b) BSS Transition Management: This mechanism complements the BSS Termination Notification one by allowing an AP to indicate to its connected stations the target APs they could potentially handover. This mechanism can be used both for energy consumption and load balancing.

### 12.7.3 MTC Energy Saving Enhancements

MTC-specific enhancements for ES are introduced in 802.11ah amendment [35], focusing on MAC mechanisms MTC for low-power devices in the ISM 90 MHz band. Operating below 1 GHz, 802.11ah technology enables APs with very large coverage. Thus, a single AP could assist many MTC devices, in the order of thousands, for example, for remote metering purposes. The support of such a huge number of devices raises several ES issues especially at the MAC layer. The following mechanisms are discussed in the 802.11ah Working Group to address these issues:

- (a) Grouping of stations: This mechanism allows an AP to create groups of stations, and assign to each group a specific time interval, wherein the stations of the group are allowed to transmit. This mechanism improves the network efficiency, including ES, by decreasing the contention overhead, or hidden nodes, and also enables stations to sleep when their group is not active.
- (b) Target Wake Time (TWT): This mechanism is an extension of the previous one, which allows an AP to communicate to a specific station the time instants, wherein this specific station is allowed to transmit. Like in the grouping case the station can efficiently sleep when it is not transmitting. The TWT parameters are typically negotiated between the station and the AP.
- (c) Two-Hop Relay Function: MTC communications can be limited in the uplink by the scarce transmission power of the sensor devices. Thus, 802.11ah allows sensor devices to communicate with the AP through a relay node.

It should be noted that since the 802.11ah specification is still under discussion (at the time when this chapter was compiled), the previously discussed mechanisms are subject to change.

## 12.8 Conclusions

This chapter provides an overview of the main standardization efforts regarding ES considering both licensed and unlicensed spectrum concentrating on 3GPP and IEEE 802.11/ Wi-Fi Alliance. NGMN created an early momentum for ES in LTE considering network management requirements and OPEX reduction. 3GPP explored the technical details considering network architecture and management, analysing also radio and protocol issues with the fundamental scenarios concentrating on overlaid, capacity limited, that is, pure LTE, and mixed scenarios including different RATs. To facilitate ES, power states were introduced for base stations mainly by the RAN and network management groups. OAM requirements and management processes were also introduced, while the RAN groups explored DTX and MIMO, with current

efforts focusing on heterogeneous deployments and on QoS considerations. The architecture group provided an ES study concentrating on core network elements, while the core network signaling analysed the handover processes when ES is applied. Further efforts for ES concentrate on MTC, while efforts influencing ES include RAN sharing and Proximity Services. GSMA provides energy efficiency benchmarking services, with the Mobile's Green Manifesto contributing the latest details. ETSI and ATIS mainly specify ES measurements and metrics, with the EEF and TEER being the most significant ones. IEEE 802.11/Wi-Fi Alliance efforts concentrate on the radio interface introducing power saving methods to conserve the station's battery via PSM, U-APSD and 802.11v extensions and mechanisms to reduce AP power via Wi-Fi Direct and for enterprise environments. Current efforts concentrate on enhancements for MTC, which are still ongoing.

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