Green Mobile Network:

Energy Saving Efforts by SK Telecom and NTT DOCOMO

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Scope and purpose of this White Paper

This White Paper has been jointly developed by SK Telecom and NTT DOCOMO under the framework of collaboration between the two companies for technical studies of 5G and 5G evolution. The content of the White Paper is based on the energy saving efforts made by SK Telecom before and after its 5G system commercialization, and NTT DOCOMO has provided some of the elements in the White Paper and contributed to the finalization thereof.

SK Telecom and NTT DOCOMO believe that reducing energy consumption and introducing effective energy saving technologies in the mobile communication networks are essential to achieve carbon neutrality and to preserve the global environment. This White Paper also emphasizes the importance of concerted efforts between mobile network operators (MNOs) and equipment vendors to explore ways to reduce energy consumption and to develop relevant technical solutions. Equipment vendors and MNOs are invited to review this White Paper for further cooperation and collaboration to develop energy-efficient mobile networks.

1. Background and introduction

Climate change is a global concern, and many countries are putting a great deal of effort to reduce carbon emissions. Enterprises in every industry are taking actions for carbon emission reduction. Telecommunications industry is no exception to this trend, and MNOs are trying to achieve “Net Zero” by 2050 in sustainable and long-term ways, where some of them are making efforts to bring forward the deadline to achieve it.

Under these circumstances, MNOs need to decrease energy consumption in their networks for carbon emission rights and reduced network operation costs. As MNOs are continuously facing demands to reduce energy consumption by applying the latest technologies to their network equipment, concerted efforts between equipment vendors and MNOs are essential to explore ways to reduce energy consumption while improving the capabilities of mobile networks. More specifically, equipment vendors need to implement such designs in their equipment and software features that can achieve low energy consumption, and MNOs need to come up with ways to efficiently utilize those equipment and features and build operational expertise.

For this purpose, it is necessary to understand the current energy consumption in the existing mobile networks and the consequential carbon emissions, and then to analyze which factors affect the energy consumption. Equipment vendors and MNOs need to think about how to leverage the latest technologies for improved energy efficiency and what needs to be developed for applying energy saving technologies to their equipment.

Mobile communication networks can be divided into core, access and transport networks, and the access network is the largest energy consumer among them. Therefore, this White Paper considers energy consumption in RAN (Radio Access Network), mainly focusing on energy consumption of 5G base stations consisting of BBU (Baseband Unit) and RU (Radio Unit).

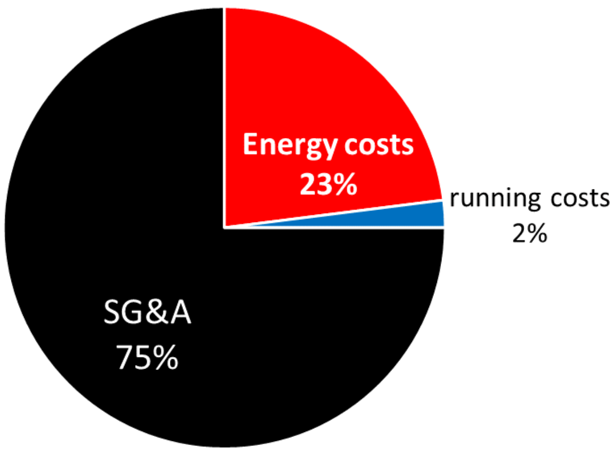
The bandwidths used in 5G systems are wider than those in the previous 2G, 3G and 4G systems, and this leads to the use of higher frequency bands. However, since the use of higher frequency bands means smaller cell coverage, it is necessary to use features that improve the coverage, such as beamforming, which increases coverage and throughput with MIMO technology which transmits signals through several antennas simultaneously. To implement the MIMO technology, AAUs (Active Antenna Unit) consisting of massive antenna elements are often used for 5G systems operating in the higher frequency bands. In general, the maximum energy consumption of 5G networks using AAU is greater than that of the previous generation networks using PRUs (Passive antenna RF Units). Thus, this White Paper investigates the energy consumption of 5G equipment currently used in the commercial networks.

This White Paper also analyzes various energy saving technologies considering the two aspects – hardware and software. Furthermore, it considers the measurement methods for the energy consumption of equipment, the KPIs (Key Performance Indicators) for energy consumption of equipment, the monitoring of energy consumption in mobile networks and the process for introduction of energy-efficient features and equipment in commercial networks.

2. Energy consumption in mobile communication networks

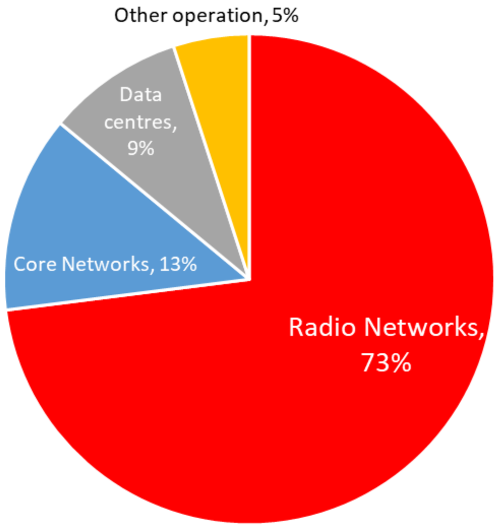
2.1 Overview of network energy consumption

Energy consumption of mobile communication networks occupies a large part of network cost for MNOs. As seen in Figure 2.1 below, which is reproduced from the analysis in [1], the energy costs account for 23% of the total network costs.



[Figure 2.1] Analysis of network costs presented in [1]

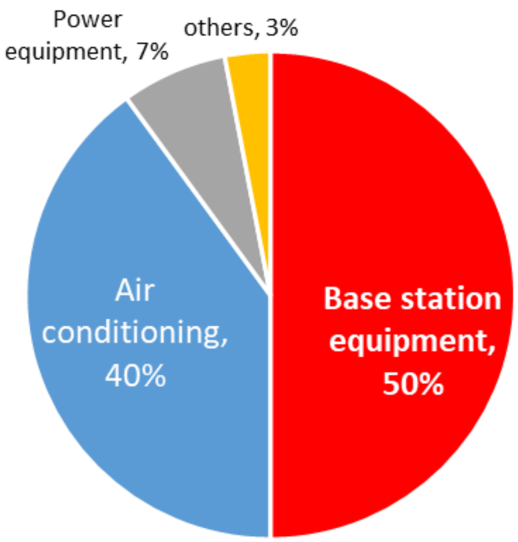
Figure 2.2 below, which is reproduced using the information available in [2], shows the amount of energy consumption by each part of MNO networks, and it turns out the RAN energy consumption is 73% of the total energy consumption.



[Figure 2.2] Analysis of energy consumption in mobile networks presented in [2]

The reason why RAN consumes more energy than other parts of the mobile networks is because the equipment in RAN, such as base stations, absolutely outnumber the equipment in other parts of the networks. Although the number of base stations increases in proportion to service coverage expansion, this is necessarily not the case with the equipment in the core network.

Figure 2.3 below, which is reproduced using the information available in [3], shows the amount of energy consumption by different types of equipment in RAN. Base station equipment accounts for 50% of the total energy consumption, followed by air conditioning equipment, which consumes 40%.



[Figure 2.3] Energy consumption analysis of base station [3]

Considering that the air conditioning equipment is necessary to prevent the base station equipment from heating up, a key to reduce energy consumption is to decrease the energy consumption of base station equipment in the first place and increase its energy efficiency.

The base station equipment consists of two parts.

- **BBU** performs baseband processing.
- **RU** converts baseband signals to radio signals or vice versa for transmission or reception over antennas.

Table 2.1 shows a comparison of energy consumption between BBUs and RUs of various types of equipment used by SK Telecom. In the case of the maximum cell load (100%) condition, the amount of power consumed by BBU is 22% whereas that by RU is 78%. Under the condition of commercial network operations, the energy consumption of 5G RU takes up 88% while LTE accounts for 82%. These percentages would change depending on the load of digital processing parts and the utilization of radio resources.

	Energy consumption per 5G cell (Maximum cell load condition)	Energy consumption in a 5G commercial network	Energy consumption in a LTE commercial network
RU	78%	88%	82%
BBU	22%	12%	18%

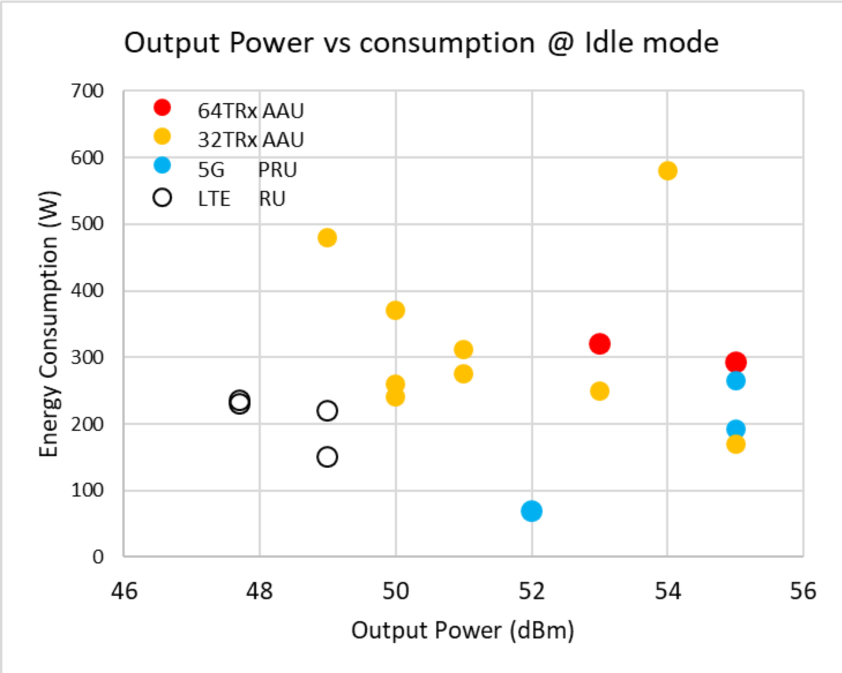
[Table 2.1] Comparison of energy consumption between RU and BBU

As shown in the above table, RU has a greater impact on the energy consumption compared to BBU in a network. Therefore, improvement of energy efficiency of base station equipment, particularly RU, should be a top priority in reducing the energy consumption in a network.

2.2 Energy consumption of 5G Radio Unit (RU)

In general, 5G equipment consumes more energy due to its increased number of transmitters in the case of massive MIMO, which is 8-16 times more than LTE, and to its increased channel bandwidths, which are 5-10 times more than LTE. It is inevitable that equipment's output power increases to improve its performance, and hence, simultaneous efforts to reduce energy consumption are required to reduce carbon emissions.

SK Telecom and NTT DOCOMO carried out energy consumption tests for various types of RUs under the same measurement conditions and methodology. In the tests, energy consumption of RUs was measured when they were in the idle mode, but not in the maximum traffic load condition. This is because, in an actual commercial network, the traffic load becomes its maximum level only in some specific areas and at specific times, and most of the base stations often remain in the idle mode during the 24 hours. Therefore, it would make more sense to compare the energy consumption when RUs are in the idle mode and to accurately analyze their amount of energy consumption.

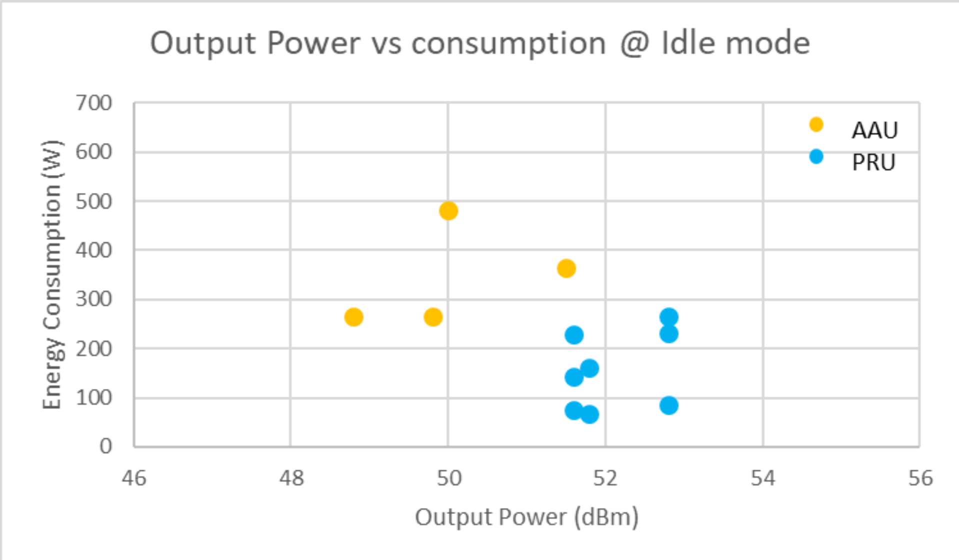


[Figure 2.4] Measurement of 5G and LTE RU energy consumption by SK Telecom

Figure 2.4 illustrates the relationship between the measured output power and the energy consumption of each of the 5G and LTE RUs in the test conducted by SK Telecom. For 5G RU, PRU and AAU which uses Massive MIMO were compared, and LTE RU tests were also conducted under the same conditions to compare LTE RU with 5G RU. Measurement of the energy consumption of each RU was conducted in the idle mode. It should be noted that even in the idle mode, the control channel's output power is transmitted, and the digital processing parts of RU are being used. As these factors contribute to the increase of output power, its overall energy consumption also increases linearly.

As shown in Figure 2.4, 5G AAU consumes more power than LTE RU in general. On the contrary, given the increased output power compared to LTE's output power, the energy consumption of 5G PRU is similar or slightly improved compared with that of LTE RU.

In fact, it is natural that 5G AAU consumes more power than 5G PRU and LTE RU as 5G AAU uses more Tx and Rx ports (e.g., 32TRx, 64TRx) than LTE RU to maximize the effect of Massive MIMO. What is more noticeable is that, among the different 5G AAUs, they show differences in transmit output power and energy consumption levels even when the same number of Tx and Rx ports are considered. On the other hand, regardless of the equipment type, LTE RU shows similar transmit output power and energy consumption levels. To be more specific, some 5G AAUs consume more power when they transmit lower output power while others consume less power even though they transmit higher output power.



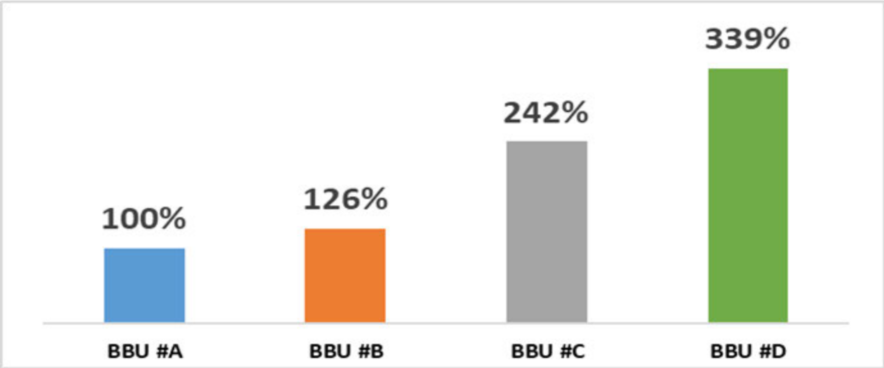
[Figure 2.5] Measurement of 5G RU energy consumption by NTT DOCOMO

Figure 2.5 shows the relationship between the measured output power and the energy consumption in the idle mode of each 5G RU obtained through the test conducted by NTT DOCOMO. As shown in the figure, AAU consumes more power compared to PRU. Furthermore, when the different RUs are compared within the same types (i.e., AAU or PRU), their values of power consumption are different. This means that there is still some room to improve the energy efficiency for such RUs that consumes more power.

2.3 Energy consumption of 5G Baseband Unit (BBU)

BBU is a node that processes baseband signals in base stations and manages call processing between the core and RU equipment. Generally, one BBU interworks with multiple RUs to process radio signals for RU. This means BBU consumes more power in proportion to the number of RUs and the amount of signaling to be processed according to the traffic loads.

The number of RUs accommodated in BBU varies depending on the type of equipment. Therefore, when comparing the energy efficiency between different types of BBU, it is essential to consider the number of cells per BBU and to compare how much each cell consumes energy. In other words, given the same amount of energy consumption, BBUs that accommodate more cells are more energy efficient.



[Figure 2.6] 5G BBU energy consumption per cell

Figure 2.6 above shows per-cell energy consumption of different 5G BBUs. Similar to the 5G AAU case, the results show differences in their energy efficiency depending on the BBU type, and it seems that there is a room to improve for energy consumption for some BBUs.

These differences in energy consumption are due to how each type of BBUs are implemented. For instance, BBU configuration for vRAN is based on a general-purpose server whereas a regular BBU consists of components that exclusively designed. In addition, since the energy consumption of BBU is affected by traffic load and power consumption in each functioning part, any relevant software features that help reducing energy use and minimizing any performance degradation will make a big difference. Such features as cell off, channel card off, and model off will reduce the BBU's energy consumption.

3. Consideration of energy saving features from hardware aspect

3.1 RU

As previously mentioned, RU would be the biggest power consumer in mobile networks, and 5G AAU consumes around 2-4 times more energy than LTE RU. This tells us that reduction of energy consumption in RU is essential to save overall network energy consumption.

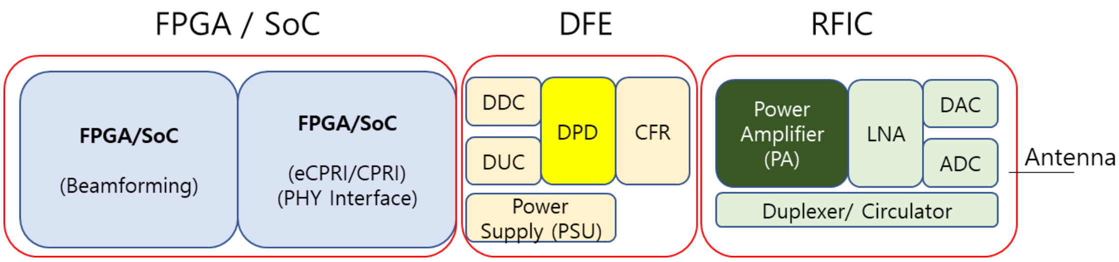
As for the energy consumption of RU's components with different traffic loads, in the case of 100% load, a power amplifier takes up more than 50% of the overall RU energy consumption. Meanwhile, in the idle mode, a power amplifier consumes less power, and the amount of power consumed by the digital IF, signaling and power module accounts for more than 40% of the overall energy consumption. Therefore, there should be ways to increase energy efficiency of the equipment that consumes less power in the low traffic loads, such as by improving the digital IF power efficiency.

Table 3.1 below is a list of major design factors that determine RU's energy consumption.

	Item	Key Factor
1	Main chipset used	FPGA or SoC
2	Number of digital chipsets	How many digital chipsets are required?
3	Number of Tx/Rx	Tx/Rx antenna array per Digital Pre-Distortion (DPD)
4	Power amplifier element	LDMOS or GaN
5	Others	Circuit, fan, etc.

[Table 3.1] Major design factors to minimize RU energy consumption.

The following parts discusses the aspects related to energy consumption considering the block diagram of RU shown in Figure 3.1.



[Figure 3.1] Block diagram of RU

- FPGA/SoC

The Chipsets in RU process RF signals, and either FPGA (Field-Programmable Gate Array) or SoC (System-on-Chip) is used.

FPGA is a programmable and general-purpose chipset. There are various models of FPGA with the different numbers of gates embedded in the elements and the I/O ports as well as the clock speed, and their performance varies depending on the models. As much as FPGA can be versatile as a general-purpose chipset, it may end up consuming more power. This is because some parts that are not used for communication still consume power. Depending on the purpose, FPGA could also consume more power as it may need to use many numbers of chipsets.

On the other hand, SoC is exclusively developed for a specific purpose or functionality. While SoC, unlike FPGA, cannot change its configuration to serve different purposes once developed, it generally consumes relatively less power than FPGA as it can minimize the operation of digital parts that are not used.

In conclusion, SoC, as a high-performance chipset, is more energy efficient than FPGA.

- DPD

DPD (Digital Pre-Distortion) is a key technology to obtain the linearity of a power amplifier. By adequately pre-distorting the input signals at the amplifier's input side, the signals are generated from the output side while keeping their linearity.

5G can allocate a wider channel bandwidth than 4G and needs to be designed to avoid signal distortion even when a wide channel bandwidth, such as 400 MHz, is used. In the case of using multi-bands, the coherence bandwidth must be guaranteed without any signal distortion. In addition, 5G must be designed to maintain the linearity when many power amplifiers are used for Massive MIMO.

DPD plays an important role for these aspects, and by realizing the linearity of power amplifier, the energy efficiency is improved.

- Power amplifier

Power amplifier has a non-linear characteristic between input and output. Due to this non-linear characteristic, unwanted interferences to the adjacent channels occur. This characteristic also causes in-band distortion that deteriorates EVM (Error Vector Magnitude).

To avoid unwanted adjacent interferences and to enhance EVM, the operating point of a power amplifier needs to be lower than its maximum level. However, this leads to severe degradation of energy efficiency. For example, it can even lose more than 90% of the power, which is converted to heat. It is therefore crucial to maintain the energy efficiency of a power amplifier at a higher level.

As for the elements for a power amplifier, LDMOS (Lateral Double-diffused Metal Oxide Semiconductor) and GaN (Gallium Nitride) are mainly used. While LDMOS is inexpensive and highly linear, it is known to be inefficient in the high frequency bands compared to GaN. GaN is approximately 10% more energy efficient than LDMOS and is known to work well, especially in the high frequency bands. It is desirable to use GaN to achieve higher energy efficiency.

3.2 BBU

BBU shows different energy consumption levels depending on how its units are designed. The processors and modems used in BBU are also related to the overall optimization of energy consumption. There is a difference between a modem designed with FPGA only and an element that includes SoC/ASIC process.

Since BBU equipment is mostly made of digital elements, the architecture or design of BBU will lead to different energy consumption levels. Some equipment types of BBU support an extra power saving feature depending on their formfactor and chipset design.

	Item	Key Factor
1	Modem	Number of chipsets (FPGA, SoC/ASIC)
2	Energy saving of a card	Channel card on/off
3	Energy saving function	Processor on/off
4	Integration	Separated or built-in channel card

[Table 3.2] Major design factors to minimize BBU energy consumption.

4. Consideration of energy saving features from software aspect

4.1 Overview of various energy saving features

To reduce energy consumption of mobile communication networks, it is important to apply appropriate software features in a base station that can be properly utilized considering its operational circumstances. In other words, energy saving software features should be developed in a way that they can decrease energy consumption of equipment without degradation of service quality offering.

Furthermore, according to each type of the equipment, there should be different levels of readiness for the energy saving features that can be used in a commercial network, and the introduction timing of them will vary accordingly. Therefore, these features should be carefully introduced and utilized in consideration of a purpose and an environment.

- Micro Sleep

For energy consumption reduction, base stations can be put into a sleep mode during the period when they transmit no data until they come back to an active mode for next data transmission. This means that Micro Sleep is effective in reducing energy consumption if more components in base stations go into a sleep mode when there is a low amount of traffic. In LTE networks, however, there is a lot of energy consumption due to regular transmissions of PSS (Primary Synchronization Signal), SSS (Secondary Synchronization Signal), PBCH (Physical Broadcast Channel), and CRS (Cell-specific Reference Signal) even when without active users. In addition, the sleep mode in LTE lasts for less time durations as it takes more time to transmit the same size of data compared to 5G. Unlike LTE, 5G equipment transmits SSB (Synchronization Signal Block) only when there is no active user, making it possible to use less energy during the idle mode. Higher throughput of 5G compared to LTE helps to reduce energy consumption by maintaining a short duration of the active mode when transmitting the same size of data. Furthermore, Non-Standalone (NSA) mode in 5G can be effective in reducing energy consumption as it only allows access to 5G for those active users having data, which helps to extend the durations of a sleep mode for 5G equipment.

Micro Sleep is a feature that can be frequently applied regardless of time and location, and it has less impact on the services under operation.

- Deep Sleep

Deep sleep is a feature that turns off not only the RF power of RU, but also other components, such as chipsets. This means the more components in RU are in a sleep mode and more energy can be saved, but it will take more time to be activated from a sleep mode. In the case of a data transmission suddenly required in a deep sleep mode, it may be difficult to quickly recover from a deep sleep mode and handle the data transmission, which may consequently have an impact on the service quality in the mobile networks.

Due to these risks, Deep Sleep can be used during specific hours or in specific environments where there will be no expected data transmissions.

- Light Sleep

Light Sleep can save power by turning off the RF power of RU. As it turns off less elements than Deep Sleep, it can be turned on immediately when necessary. When the dual frequency bands are used, Light Sleep can better cope with a sudden traffic surge in a short time compared to Deep Sleep.

However, if it fails to notice any sudden traffic changes when using a single frequency band, Light Sleep would be as risky as Deep Sleep.

- MIMO Sleep

MIMO Sleep turns off parts of RF chains. This feature can be turned on for 24 hours if traffic monitoring is always enabled. If the digital parts are turned off, depending on how the equipment is implemented, it is possible for MIMO Sleep to save more energy.

There is also a challenge in MIMO Sleep. For the time being, it is either difficult to implement this software feature in the equipment or it may cause degradation of network performance even if it is implemented. However, MIMO Sleep will be effective for massive MIMO, which increases the number of antennas to be used and consequently consumes more power. Development and implementation of the relevant algorithms for MIMO Sleep are encouraged.

- Envelope Tracking [4]

Envelope tracking reduces the use of excessive power of input voltage by varying the input voltage according to the level of amplifier output. When the input voltage is consistently supplied, all the energy except for that required by the amplifier is dissipated as heat. In this case, adding hardware for a feedback logic and adjusting input voltage according to the amplifier output will reduce energy loss and save more power.

Envelope Tracking can also be always turned on and does not affect network quality. However, adjusting the input voltage according to constantly varying output power is a difficult control to be achieved. There are many studies being conducted and further enhancement of hardware is also necessary to implement the relevant software features for Envelope Tracking. A continuous development effort for Envelope Tracking is encouraged to increase the energy efficiency.

4.2 Comparison of various energy saving features

Micro Sleep can quickly wake up to handle sudden data transmission and reduce service quality degradation. However, its energy consumption reduction effect is still limited. Deep Sleep is the most effective for energy saving as it turns off many components including the RF and the digital processing parts. However, this feature is not always applicable due to its impact on call processing and service quality in a network, in particular, when a single frequency band is used in the network.

Considering the various aspects, Envelope Tracking would be a promising solution to reduce energy consumption as it can be always applicable in a mobile network without degradation of service quality. Envelope Tracking would be a feature that should be further studied, developed and implemented in commercial equipment as a top priority.

5. How to measure energy consumption

To investigate how much energy is consumed in equipment, it should be measured under the two different conditions, i.e., when the equipment is in the idle mode condition and in the full traffic load condition, respectively. The measurements of the minimum and maximum energy consumption levels of equipment under these conditions helps to identify how much energy is consumed in the equipment itself and to assess how much energy can be saved after applying certain energy saving features.

In actual commercial networks, the amount of generated traffic varies between the full and empty loads, depending on time, number of users and coverage size. Therefore, the measurement results of energy consumption considering an actual traffic load in a commercial network environment will be more realistic ones.

Since the LTE operation was initiated, SK Telecom has been implementing its energy consumption measurement methods and improving them to become more accurate. These methods are shared with all the equipment vendors who supply their equipment to SK Telecom, and they are required to measure the energy consumption of the equipment and provide the results to SK Telecom.

6. KPIs of energy consumption for equipment

Energy consumption of every equipment will vary depending on the completion level of equipment design and the various technical features implemented by equipment vendors. Therefore, defining proper KPIs regarding energy consumption is beneficial, and these KPIs can be used to assess the level of each vendor's capability.

When defining these KPIs, it is also necessary to consider achievable performance of equipment. For example, the output power of 5G AAU is higher compared to that of PRU. On the other hand, 5G AAU equipment can offer more accurate beamforming effect and provide higher throughput performance. Therefore, it is not fair to apply the same energy consumption KPIs between 5G AAU and PRU.

MNOs, with collaboration with equipment vendors, need to define a set of energy consumption KPIs that account for equipment type and its usage in different environments.

7. Monitoring of energy consumption in mobile networks

7.1 Importance of energy consumption monitoring in mobile networks

Monitoring of each energy-saving feature in detail is important to increase energy consumption efficiency, but at the same time, it is also important for MNOs to analyze the total energy consumption in their networks. While all the energy saving features, such as Micro Sleep, are effective and useful in general, it would not be the best way to use them in the same manner. Depending on an MNO's environment, the energy saving features should be utilized in various manners while maximizing the reduction of energy consumption and maintaining the required service quality.

It is important to monitor energy consumption status of an MNO according to respective service areas and types of equipment. It is also essential to ensure that the energy consumption of the equipment in operation is managed within the benchmarks. To this end, a dashboard that can provide proper energy management is beneficial for MNOs. The dashboard calculates and displays monthly, daily and hourly trends of energy consumption for each service area and each type of equipment. When different patterns of energy consumption trend are detected, the relevant measures can be taken to resolve any issues in the features or equipment in operation. In addition, after applying the energy saving features, it is possible to assess their overall effects and come up with more ways to maximize their effectiveness.

In most cases, equipment vendors can provide with statistical data of energy consumption of their equipment. If the data is highly reliable, it is possible to calculate the amount of energy consumption in a network and reflect it to the forecasting model of energy consumption.

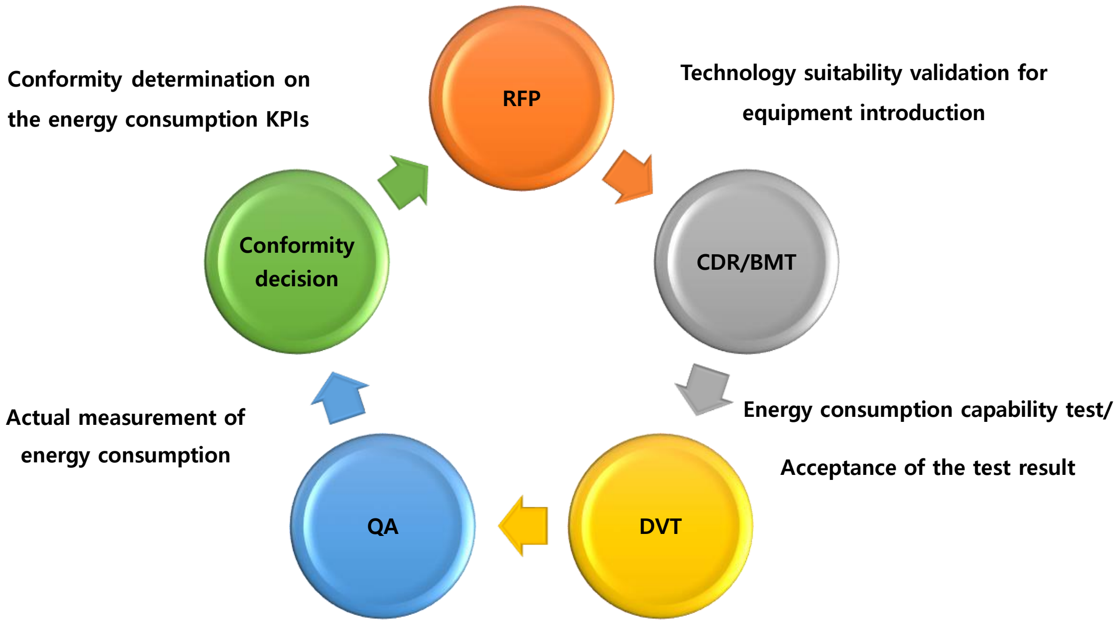
7.2 AI based monitoring for energy saving

While the above-mentioned features in Section 4 can reduce energy consumption, their achievable reduction levels are different depending on how they are used. Each feature can be used for different purposes based on their characteristics. For example, Deep Sleep can also be applied to 5G BBU, but it can only be enabled at a few selected low-traffic load base stations during off-peak hours and/or in areas where traffic offload to other networks, such as LTE, is possible. Light Sleep can also be applied in the selected areas at off-peak hours together with continuous generated traffic monitoring.

Some MNOs feel the need to continuously monitor and manage various operational environments, and consequently, have introduced their own solutions for these purposes. For instance, SK Telecom has introduced its own AI-based in-house solution which is currently up and running. Without manual operations, this AI-based solution learns by itself – it monitors traffic for a week to predict the daily/hourly/minute-by-minute traffic volumes and selects the most appropriate energy saving features and their application time. If the solution proves to be effective, it will be applied to more RUs and be utilized without jeopardizing data transmission quality. This is one of the efforts by SK Telecom to gradually reduce CO_2 emissions. In addition, unusual power surge or drop that deviate from the usual patterns is continuously monitored for area- or site-based analysis. With such an analysis, SK Telecom is exploring ways to further decrease energy consumption in the mobile network.

8. Process for introduction of energy-efficient features in commercial networks

Since it takes some time for energy saving features to be implemented and applied to commercial networks due to the required series of tests, it may not be possible to adopt these features in a timely manner. For this reason, it is crucial for MNOs to agree with equipment vendors in advance with respect to the equipment design for energy saving, introduction plan to the commercial networks and process to avoid any unexpected issues.



[Figure 7.1] Process for introduction of energy saving features in commercial networks

The illustrated process in Figure 7.1 can be used when MNOs introduce new equipment. During the conformity validation, MNOs check if the equipment includes energy-saving capability. Then, energy consumption of the equipment is measured in the test. This is a set of procedures that determine if the equipment meets the energy consumption KPIs. Applying this process will create a positive cycle for continuous introduction of low-power equipment by MNOs. Furthermore, these systematic procedures from the planning to the delivery of the equipment would help the equipment vendors to introduce proper low-power designed equipment.

After adopting new equipment, MNOs will keep using it for a long time until the equipment goes out of order. In the first place, it is crucial for MNOs to procure equipment with low-power design that can be used for a long time.

9. Conclusion

Telecommunications industry is facing demands to reduce energy consumption by applying the latest technologies to their equipment and improving the structures of their networks. SK Telecom and NTT DOCOMO believe that reducing energy consumption and introducing effective energy saving technologies in the mobile communication networks are essential to achieve carbon neutrality and to preserve the global environment.

Based on the discussions presented in this White Paper, SK Telecom and NTT DOCOMO would like to summarize our considerations as follows:

- Rather than individual efforts by equipment vendors and MNOs, concerted efforts between them are required to explore ways to reduce energy consumption while improving the network capabilities.
- Equipment vendors should design and implement energy efficient equipment and associated

software features while MNOs should utilize them effectively and build operational expertise.

- Equipment vendors and MNOs should continue studies on how to utilize the latest energy saving technologies for improved energy efficiency and how to apply them to the equipment and networks. According to the measurements and analyses conducted by SK Telecom and NTT DOCOMO, there are some gaps in the implemented features and the energy saving capabilities among different vendors' equipment and there is still room to improve energy consumption in the equipment. Furthermore, monitoring of energy consumption in a network is becoming more important for MNOs.
- To further reduce energy consumption, equipment vendors and MNOs should also investigate new solutions and adopt these solutions in the networks in a seamless manner. To achieve this, it is necessary to develop a common understanding on the measurement methods of equipment, the KPIs for energy consumption and the process for introduction of features and equipment in the commercial networks.

Acronyms

AAU	Active Antenna Unit
AI	Artificial Intelligence
ASIC	Application Specific Integrated Circuit
BBU	Baseband Unit
BMT	Benchmark Test
CDR	Critical Design Review
CRS	Cell-specific Reference Signal
DPD	Digital Pre-Distortion
DVT	Developer Validation Test
EVM	Error Vector Magnitude
FPGA	Field-Programmable Gate Arrays
GaN	Gallium Nitride
I/O	Input/Output
IF	Intermediate Frequency
KPI	Key Performance Indicator
LDMOS	Lateral Double-diffused Metal Oxide Semiconductor
LTE	Long Term Evolution
MIMO	Multi Input Multi Output
MNO	Mobile Networks Operator
NSA	Non-Stand Alone
PBCH	Physical Broadcast Channel
PRU	Passive Antenna RF Unit
PSS	Primary Synchronization Signal
QA	Quality Assurance
RAN	Radio Access Network
RF	Radio Frequency
RFP	Request for Proposal
RU	Radio Unit
Rx	Receiver
SoC	System-on-Chip
SSB	Synchronization Signal Block
SSS	Secondary Synchronization Signal
TRx	Transceiver
Tx	Transmitter
vRAN	Virtualized RAN

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