Small Data Transmission (SDT): Protocol Aspects

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Signals for transitioning to a radio resource control (RRC) connected state and maintaining the RRC connected state could cause overheads (e.g., power consumption and delay) to a wireless device having small amount of data to transmit when in an RRC idle state or an RRC inactive state.

3rd Generation Partnership Project (3GPP) has introduced technologies to reduce the overheads. This article gives a brief introduction of the technologies and investigates a protocol aspects of the technologies.

1. Introduction

Before technologies to reduce overheads for small data transmission (SDT) is introduced for long-term evolution (LTE) or new radio (NR), uplink (UL) data generated in an RRC idle state can be transmitted only after transitioning to an RRC connected state according to 3GPP specifications. After transmission of the UL data, a wireless device in the RRC connected state needs to receive an RRC release message for transitioning back to the RRC idle state.

Figure. 1 illustrates an overall procedure from generation of the UL data in an RRC idle state to transitioning back to the RRC idle state.

According to the 3GPP specifications, when a wireless device in an RRC idle state has UL data, the wireless device should perform procedures for the transmission of the UL data where the procedures comprises:

- a random access procedure to synchronize uplink timing [1][2];
- a radio resource control (RRC) connection establishment procedure to establish an RRC connection [3][4]; and
- an initial access stratum (AS) security activation procedure for secured data transmission [3][4].

When the procedures is successfully completed, the wireless device in an RRC connected state transmits the UL data. After the transmission of the UL data, the wireless device stays in the RRC connected state until receiving an RRC release message from a base station. While staying in the RRC connected state, the wireless device should perform additional procedures (e.g., radio link monitoring (RLM), measurement & measurement reporting, etc.). The wireless device transitions back to the RRC idle state when receiving an RRC release message from the base station.

The procedures for the transmission of the UL data could not be appropriate for SDT. The overheads of the overall procedure are inefficient to transmit small amount of data (small data). The overheads become more critical especially for a device requiring low complexity and low power consumption. Thus, 3GPP has introduced technologies to reduce the overheads.

This article organized as follows: Section 2 describes cellular internet of things (CIoT) optimization which supports early data transmission after transitioning to an RRC connected state. Section 3 describes SDT technologies which supports data transmission without transitioning to an RRC connected state. Section 4 provides a summary.

2. CIoT optimization

3GPP introduced a suite of two complementary

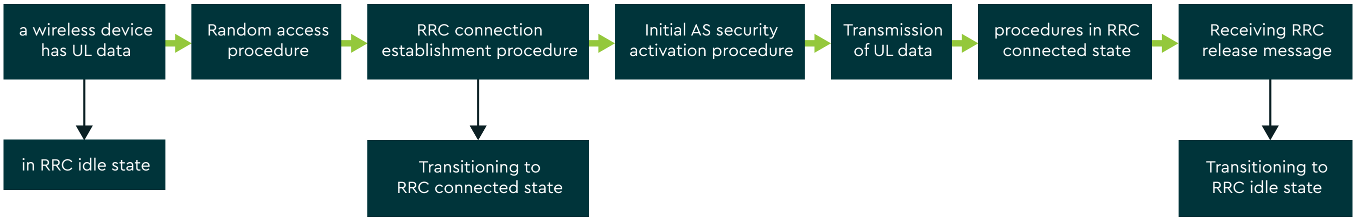

FIG. 1 Overall procedure from generation of UL data in RRC idle state to transitioning back to RRC idle state

narrowband LTE internet of things (IoT) technologies in Release 13: eMTC (enhanced machine-type communication) and NB-IoT (narrowband internet of things). Both are optimized for lower complexity/power, deeper coverage, and higher device density, while seamlessly coexisting with other LTE services such as regular mobile broadband.

3GPP introduced cellular internet of things (CIoT) optimization to reduce overheads for data transmission of eMTC devices and NB-IoT devices [3]. The CIoT optimization enables a wireless device to transmit data right after transitioning to an RRC connected state. Based on the CIoT optimization, a wireless device can transmit data without performing the initial AS security activation procedure shown in Figure 1.

The CIoT optimization comprises user plane (UP) CIoT optimization; and control plane (CP) CIoT optimization. A wireless device transmits data via a user plane using the UP CIoT optimization and via a control plane (CP) using the CP CIoT optimization, respectively. For the UP CIoT optimization, a suspension of an RRC connection and a resumption of an RRC connection are introduced. The suspension of the RRC connection is initiated by a base station. When the RRC connection is suspended, a wireless device and the base station stores current configuration parameters (e.g., AS security parameters), a resume identity, and a next hop chaining count (NCC) for an AS security activation in next access. The resumption of the suspended RRC connection is initiated by the wireless device. When the RRC connection is resumed by the RRC connection establishment procedure, the wireless device (re)activates an AS security based on the NCC and the AS security parameters.

For the CP CIoT optimization, data is integrity protected and/or ciphered by a non-access stratum (NAS) security of a NAS layer. The AS security activation is not required for the CP CIoT optimization. The CP CIoT optimization enables a wireless device to transmit the data via an RRC complete message of the RRC connection establishment procedure. The RRC complete message comprises a NAS message which includes the data and release assistance information (RAI). The RAI indicates expected traffic pattern: only one UL transmission being expected;

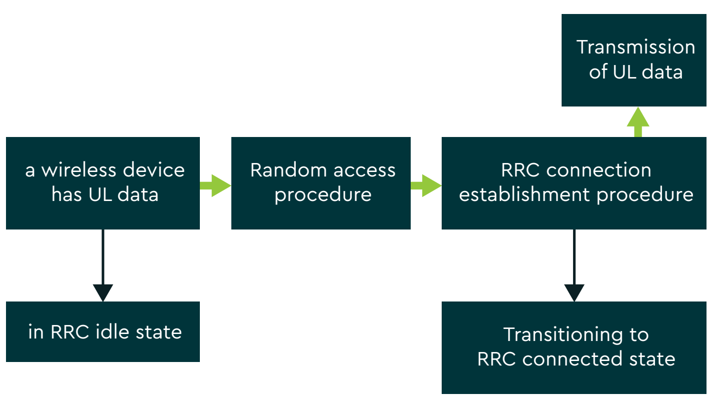

FIG. 2 CIoT optimization procedure for transmission of UL data being generated in RRC idle state

or one UL and one downlink (DL) transmission being expected. The RAI enables a network to transition the wireless device to an RRC idle state or an RRC inactive state as early as possible. It can reduce overheads from the additional procedure in the RRC connected state by reducing the duration of a time the wireless device stays in the RRC connected state.

3. Small Data Transmission (SDT)

Based on the CIoT optimization, 3GPP has developed technologies for SDT to support data transmission without transitioning to an RRC connected state. 3GPP introduced SDT technologies for 4G LTE in Release 15 and Release16, and for 5G new radio (NR) in Release 17.

A. SDT for 4G LTE

The SDT technologies for 4G LTE include early data transmission (EDT) and transmission using pre-configured uplink resource (PUR). 3GPP introduced the EDT in Release 15 and the transmission using pre-configured uplink resource (PUR) in Release 16 [3]. The EDT enables a wireless device to receive uplink grant for SDT in an RRC idle state via an random access procedure for the EDT. The wireless device in the RRC idle state transmits UL small data using the uplink grant. The transmission using PUR allows SDT from an RRC idle state using PUR without performing a random access procedure.

A wireless device in an RRC idle state performs the EDT or the transmission using PUR by transmitting UL small data via Msg 3. The Msg 3 comprises the UL small data and an RRC request message of the RRC connection establishment procedure. The wireless device determines that the EDT or the transmission using PUR is successfully completed, when the wireless device in the RRC idle state receives a response message (e.g., Msg 4) from a base station. The Msg 4 comprises an RRC response message and/or DL small data. The wireless device transitions back to the RRC idle state or transitions to an RRC inactive state when receiving the Msg 4. Figure 3 illustrates the SDT technologies for 4G LTE. In Figure 3, a wireless device performs a random access procedure for the EDT to receive uplink grant for SDT. For the transmission using the PUR, a wireless device transmits UL small data using PUR without performing a random access procedure.

The EDT comprises UP EDT and CP EDT. The transmission using PUR comprises UP transmission using PUR and CP transmission using PUR. Small data is transmitted via a user plane using the UP EDT or the UP transmission using PUR; or via a control plane using the CP EDT or the CP transmission using PUR.

In case of the UP EDT or the UP transmission using PUR, the suspension and the resumption of an RRC connection introduced for the UP CIoT optimization are re-used. Different from the UP CIoT optimization, an early AS security activation is required for transmission via Msg 3. The AS security is re-activated prior to transmission of the RRC request message (i.e., an RRC resume request message) using the NCC stored during the suspension of the RRC connection. UL small data is integrity protected and/or ciphered based on the activated AS security. The UL small data

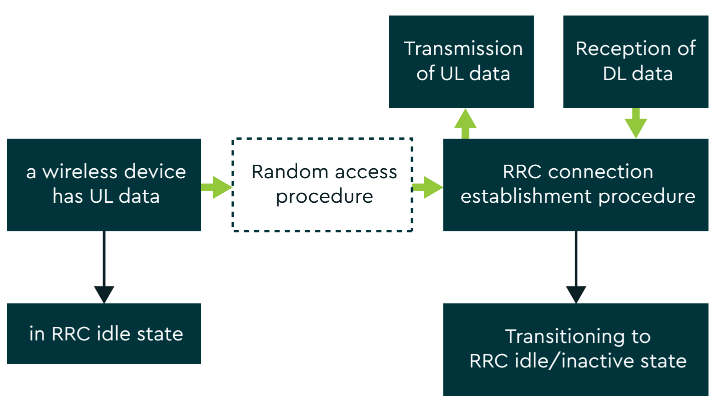

FIG. 3 SDT technologies for 4G LTE

is transmitted on a dedicated traffic channel (DTCH) multiplexed with the RRC Request message on a common control channel (CCCH). In the downlink, DL small data, if available, are transmitted on a DTCH multiplexed with the RRC response message (i.e., an RRC release message) on a dedicated control channel (DCCH).

In case of the CP EDT or the CP transmission using PUR, UL small data is included in the RRC Request message (i.e., an RRC early data request message). DL small data is included in the RRC response message (i.e., an RRC early data complete message), if available, and sent over signaling radio bearer 0 (SRB0).

B. SDT for 5G NR

The SDT technologies for 5G NR were introduced in Release14. In NR study item of Release 14, there was a short discussion on technologies for NR SDT in an RRC inactive state [5]. However, the discussion in Release14 did not lead to a normative work.

For Rel-17, 3GPP approved a work item on NR SDT in an RRC inactive state [6]. This work item supports two SDT technologies: RACH based SDT; and configured grant (CG) based SDT. Similar with the EDT, the RACH based SDT allows SDT using an uplink grant received via a random access procedure for SDT. Similar with the transmission using PUR, the CG based SDT allows SDT from an RRC inactive state using a configured grant without performing a random access procedure. This work item only considers SDT via user plane like UP SDT for 4G LTE such as the UP EDT or the UP transmission using PUR.

Different from SDT in LTE, this work item investigates NR's radio frequency characteristics on SDT. For example, the radio frequency characteristics are synchronization signal block (SSB), beam, bandwidth part, etc. Besides the radio characteristics, this work item has different scopes from the UP SDT in 4G LTE. Table 1 shows comparison of the SDT for 5G NR and the UP SDT for 4G LTE.

- **RRC state:** The SDT for 5G NR considers an RRC inactive state whose operation is also based on the suspension of an RRC connection and the resumption of an RRC connection. As compared to an RRC idle state, the RRC inactive state has different features such as radio access network (RAN) based notification area (RNA), RAN paging, etc.

- **RACH & Carrier:** The SDT for 5G NR considers additionally new features introduced in 5G NR such as 2 step RACH and supplementary uplink carrier (SUL).

- **Target device/application & traffic pattern:** The SDT for 4G LTE considers eMTC and NB-IoT device requiring low complexity and low power consumption. Typical traffic pattern of the eMTC device and the NB-IoT device is one UL data; or

	SDT for 5G NR	UP SDT for 4G LTE
RRC State	RRC inactive state	RRC idle state
Target device/application	Smartphone & eMTC and NB-IoT	eMTC and NB-IoT
RACH	2 step RACH & 4 step RACH	4 step RACH
Carrier	Supplementary uplink carrier & Normal uplink carrier	Normal uplink carrier
Traffic pattern	Subsequent transmission (Multiple data transmission)	one UL data and/or one DL data
Type of bearer	Signaling radio bearer & Data radio bearer	Data radio bearer only
Base station for SDT	Non-anchor relocation & Anchor relocation	Anchor relocation only

TABLE 1 Comparison of SDT for 5G NR and UP SDT for 4G LTE

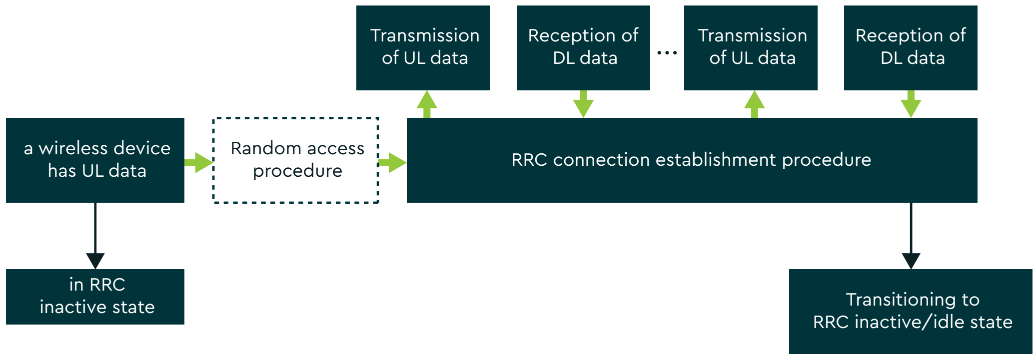

FIG. 4 SDT technologies for 5G NR: subsequent transmission

one UL data and one DL data. Thus, the SDT for 4G LTE considered one UL data transmission via Msg 3 and/or one DL data transmission via Msg 4. However, the SDT for 5G NR considers various types of devices (or applications) such as a smartphone and a wearable device. The SDT for 5G NR considers various traffic pattern including multiple data transmissions. Based on the SDT for 5G NR, a wireless device performs an initial SDT by transmitting UL small data via Msg 3/Msg A and/or receiving DL small data via Msg 4/Msg B. After receiving the Msg 4/Msg B, the wireless device continues subsequent transmission/reception without transitioning to an RRC connected state. The wireless device transitions to an RRC inactive state or an RRC idle state when successfully completing the subsequent transmission/reception. Figure 4 shows the subsequent transmission/reception of the SDT for 5G NR.

- **Type of bearer:** In the UP SDT for 4G LTE, only data of a data radio bearer (DRB) is considered for SDT. However, the SDT for 5G NR considers signals of a signalling radio bearer (SRB) for SDT. For example, 3GPP considers that positioning/location information can be transmitted via the SRB based on the SDT for 5G NR.

- **Base station for SDT:** a suspension of an RRC connection is initiated by a serving/anchor base station. Based on the suspension, the serving/anchor base station stores current configuration parameters of a wireless device in user equipment (UE) contexts. The wireless device may initiate a resumption of an RRC connection on a target/non-anchor base station different from the serving base station. The wireless device transmits a request for the resumption to the target/non-anchor base station. Upon receiving the request, the target/non-anchor base station requests the UE contexts to the serving/anchor base station. The UP SDT for 4G LTE only considered an anchor relocation case that the target/non-anchor base station becomes new anchor base station by receiving the UE context from the serving/anchor base station. The wireless device performs SDT with the new anchor base station. However, in the SDT for 5G NR, it is investigated that signals for the anchor relocation causes overheads (e.g., power consumption or delay) of the SDT. Thus, the SDT for 5G NR supports SDT without the anchor relocation (i.e., non-anchor relocation). Based on the non-anchor relocation, small data is transmitted to the serving/anchor base station via the target/non-anchor base station. The serving/anchor base station transmits the small to a core network entity, user plane function (UPF). Figure 4 shows the non-anchor relocation of the SDT for 5G NR.

4. Summary

This article investigates overheads for SDT in a protocol point of view and introduces 3GPP works

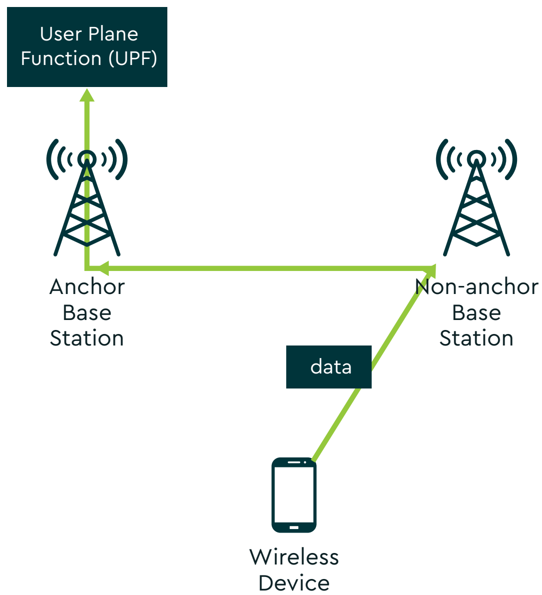

FIG. 5 SDT technologies for 5G NR: non-anchor relocation

to reduce the overheads in 4G LTE and 5G NR. In Release 13 and 14, 3GPP introduced CIoT optimization supporting early data transmission after transitioning to an RRC connected state. In Release 15 and 16, 3GPP introduced SDT technologies for 4G LTE which support data transmission without transitioning to an RRC connected state. Recently, 3GPP is working on SDT technologies for 5G NR in Release 17 and developing the existing SDT technologies for 5G NR. This article investigates protocol aspects of these 3GPP technologies introduced from Release 13 to Release 17.

References

[1] 3GPP TS 36.321: "Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification".

[2] 3GPP TS 38.321: "NR; Medium Access Control (MAC); Protocol specification".

[3] 3GPP TS 36.331: "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification".

[4] 3GPP TS 38.331: "NR; Radio Resource Control (RRC); Protocol specification".

[5] 3GPP TR 38.804: "Study on New Radio Access Technology; Radio Interface Protocol Aspects"

[6] 3GPP RP-210870: "Updated Work Item on NR small data transmissions in INACTIVE state"

About the Author:

Taehun Kim received his Ph.D in wireless communication from the Korea Advanced Institute of Science and Technology (KAIST) in Daejeon, Korea. After receiving his Ph.D, he was a postdoctoral research fellow in electrical engineering at University of California Los Angeles (UCLA) from 2011 to 2012. His experience includes; LG Electronics as a 3GPP delegate, a CT1 delegate from 2013 to 2017 and, a RAN2 delegate from 2018 to 2019. He is currently a Senior Technical Staff inventor with Ofinno, LLC. Located in Reston, Virginia. His research interests include R&D of 5G/6G systems and 3GPP standardizations.

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