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PROACTIVE SYNCHRONIZATION AND PHYSICAL BROADCAST CHANNEL SIGNAL BLOCK/ TRACKING REFERENCE SIGNAL RECEPTION PROCEDURE FOR HALF-DUPLEX OPERATION

Abstract

A method and wireless device (WD) for proactive synchronization signal and physical broadcast channel signal block (SSB)/tracking reference signal (TRS) reception procedures for half-duplex operation are disclosed. According to one aspect, a method in a WD includes determining whether a first signal reception (FSR) condition is met, the FSR condition including one of receipt and availability of at least N first signals during a time interval ΔT ending at a time T**2**, N being an integer greater than zero. The method also includes, when the FSR condition is met, operating a second signal on a radio resource at the time T**2.**

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Background/Summary

TECHNICAL FIELD
[0001] The present disclosure relates to wireless communications, and in particular, to proactive synchronization signal and physical broadcast channel signal block (SSB)/tracking reference signal (TRS) reception procedures for half-duplex operation.
BACKGROUND
[0002] The Third Generation Partnership Project (3GPP) has developed and is developing standards for Fourth Generation (4G) (also referred to as Long Term Evolution (LTE)) and Fifth Generation (5G) (also referred to as New Radio (NR)) wireless communication systems. Such systems provide, among other features, broadband communication between network nodes, such as base stations, and mobile wireless devices (WD), as well as communication between network nodes and between WDs. Sixth Generation (6G) wireless communication systems are also under development.
[0003] Wireless communication systems according to the 3GPP may include one or more of the following channels: [0004] A physical downlink control channel, PDCCH; [0005] A physical uplink control channel, PUCCH; [0006] A physical downlink shared channel, PDSCH; [0007] A physical uplink shared channel, PUSCH; [0008] A physical broadcast channel, PBCH; and [0009] A physical random access channel, PRACH.
[0010] 3GPP Technical Release 17 (3GPP Rel-17) will introduce the reduced capability (RedCap) WDs which can facilitate the expansion of the NR device ecosystem to cater to the use cases that are not yet best served by 3GPP Rel-15/Rel-16 NR specifications targeting evolved mobile broadband (eMBB) and ultra-reliable and low latency communications (URLLC).
[0011] The use cases for NR RedCap include wearables (e.g., smart watches, wearable medical devices, AR/VR goggles, etc.), industrial wireless sensors, and video surveillance. One of the key requirements for RedCap WD is the battery lifetime and device size. For example, wearable devices require at least several days and up to 1-2 weeks and industrial wireless sensors require at least a few years for the battery life.
[0012] To achieve a small device size and/or longer battery lifetime, 3GPP has considered defining RedCap WDs by considering complexity reductions such as: [0013] Bandwidth reduction, the maximum bandwidth may be limited to 20 MHz for FR1 and 100 MHz for FR2; [0014] Reducing the maximum number of MIMO layers by 1, implying a single receive antenna; [0015] Relaxation of the maximum downlink modulation order, i.e., RedCap WD does not support 256 quadrature amplitude modulation (QAM) or higher order modulation; and [0016] Allowing half-duplex (HD) operations in frequency division duplex (FDD) bands. It helps reduce the bill of material costs in terms of antennas and radio frequency (RF) components.
[0017] When the WD is in IDLE/INACTIVE state, the WD monitors the PDCCH whose transmission occasions are configured by the gNB (hereafter referred to as a network node) every discontinuous reception (DRX) cycle. The DRX cycle may be 320 ms, 640 ms, 1280 ms, and 2560 ms. 3GPP Rel-17 extends the DRX to enable a longer DRX period, called extended DRX (eDRX). With eDRX, it is possible to extend the DRX cycle up to 2.91 hours.

[0018] In NR, a new association mechanism for paging was introduced. The paging occasions are associated with a synchronization signal (SS) burst. There are two possible ways to multiplex SSB and paging occasion (PO). [0019] SSB frequency division multiplexed (FDMed) with PO; and [0020] SSB time division multiplexed (TDMed) with PO.
[0021] The summary of length and periodicity of PDCCH monitoring for different patterns are given in Table 1.
TABLE-US-00001 TABLE 1 Length of PDCCH PDCCH SFN in which Monitoring Monitoring PDCCH Monitoring Occasions Occasion Occasions are Carrier Patterns Interval per SSB located Frequency Pattern 1 Every 20 ms 2 a) SFN mod 2 = 0 FR1, FR2 consecutive for all SSBs OR slots b) SFN mod 2 = 0 for some SSBs and SFN mod 2 = 1 for others. Pattern SS burst set 1 slot SFN in which SS FR2 2/3 period burst set is (5, 10, 20, transmitted. (Note: 40, 80, SS burst set can be 160) ms transmitted in any radio frame of SS burst set period.
[0022] The paging frequency (PF) and PO for paging are determined by the following formula. First, the system frame number (SFN) for the PF is determined by:

$$(\mathrm{SFN}+\mathrm{PF\_offset})\bmod T=(T \operatorname{div} N)*(UE\_ID \bmod N)$$

[0023] Index (i_s) indicates the index of the PO, and is determined by:

$$i\_s=\mathrm{floor}(\mathrm{UE\_ID}/N)\bmod Ns$$

[0024] The PDCCH monitoring occasions for paging are determined according to pagingSearchSpace as specified in 3GPP Technical Standard (TS) 38.213 [4] and firstPDCCH-MonitoringOccasionOfPO and nrofPDCCH-MonitoringOccasionPerSSB-InPO if configured as specified in 3GPP TS 38.331 [3]. When SearchSpaceId=0 is configured for pagingSearchSpace, the PDCCH monitoring occasions for paging are same as for remaining minimum system information (RMSI), for example, as defined in clause 13 in 3GPP TS 38.213.
[0025] When SearchSpaceId=0 is configured for pagingSearchSpace, Ns is either 1 or 2. For Ns=1, there is only one PO which starts from the first PDCCH monitoring occasion for paging in the PF. For Ns=2, a PO is either in the first half frame (i_s=0) or the second half frame (i_s=1) of the PF.
[0026] When SearchSpaceId other than 0 is configured for pagingSearchSpace, the WD monitors the (i_s+1).sup.th PO. A PO is a set of 'S*X' consecutive PDCCH monitoring occasions where 'S' is the number of actual transmitted SSBs determined according to ssb-PositionsInBurst in SIB1 and X is the nrofPDCCH-MonitoringOccasionPerSSB-InPO if configured or is equal to 1 otherwise. The [x*S+K].sup.th PDCCH monitoring occasion for paging in the PO corresponds to the K.sup.th transmitted SSB, where x=0, 1, . . . , X−1, K=1, 2, . . . , S. The PDCCH monitoring occasions for paging which do not overlap with uplink (UL) symbols (determined according to tdd-UL-DL-ConfigurationCommon) are sequentially numbered from zero starting from the first PDCCH monitoring occasion for paging in the PF. When firstPDCCH-MonitoringOccasionOfPO is present, the starting PDCCH monitoring occasion number of (i_s+1).sup.th PO is the (i_s+1).sup.th value of the firstPDCCH-MonitoringOccasionOfPO parameter; otherwise, it is equal to i_s*S*X. If X>1. When the WD detects a PDCCH transmission addressed to P-radio network temporary identifier (RNTI) within its PO, the WD is not required to monitor the subsequent PDCCH monitoring occasions for this PO.
[0027] The 4-step random access (RA) procedure has been used in 4G LTE and is also the baseline for 5G NR. The principle of this procedure in NR is shown in FIG. **1**.
Step 1: Preamble Transmission
[0028] The WD randomly selects a RA preamble (PREAMBLE_INDEX) corresponding to a selected SS/PBCH block, and transmits the preamble on the PRACH occasion mapped by the selected SS/PBCH block. When the network node (NN) detects the preamble, it estimates the Timing advance (TA) the WD should use in order to obtain UL synchronization at the network node.

Step 2: RA Response (RAR)

[0029] The network node, e.g., gNB, sends a RA response (RAR) including the TA, the TC-RNTI (temporary identifier) to be used by the WD, a Random Access Preamble identifier that matches the transmitted PREAMBLE_INDEX and a grant for Msg3. The WD expects the RAR and thus, monitors the PDCCH addressed to RA-RNTI to receive the RAR message from the network node until the configured RAR window (ra-ResponseWindow) has expired or until the RAR has been successfully received.

[0030] From 3GPP TS 38.321: "The MAC entity may stop ra-ResponseWindow (and hence monitoring for Random Access Response(s)) after successful reception of a Random Access Response containing Random Access Preamble identifiers that matches the transmitted PREAMBLE_INDEX."

Step 3: "Msg3" (UE ID or WD-Specific C-RNTI)

[0031] In Msg3, the WD transmits its identifier (UE ID) for initial access. Or, if the WD is already in RRC_CONNECTED or RRC_INACTIVE mode and needs to e.g., re-synchronize, for example, the WD sends its WD-specific radio network temporary identifier (RNTI). If the network node cannot decode Msg3 at the granted UL resources, it may send a downlink control information (DCI) message addressed to TC-RNTI for retransmission of Msg3. Hybrid automatic repeat request (HARQ) retransmission is requested until the WD restarts the random access procedure from step 1 after reaching the maximum number of HARQ retransmissions or until Msg3 may be successfully received by the network node.

Step 4: "Msg4" (Contention Resolution)

[0032] In Msg4 the network node responds by acknowledging the WD ID or C-RNTI. The Msg4 gives contention resolution, i.e., only one WD ID or C-RNTI will be sent even if several WDs have used the same preamble (and the same grant for Msg3 transmission) simultaneously. For Msg4 reception, the WD monitors TC-RNTI (if it transmitted its WD ID in Msg3) or C-RNTI (if it transmitted its C-RNTI in Msg3).

[0033] The 2-step RA procedure gives much shorter latency than the ordinary 4-step RA. In the 2-step RA the preamble and a message corresponding to Msg3 (msgA PUSCH) in the 4-step RA can, depending on configuration, be transmitted in two subsequent slots. The msgA PUSCH is sent on a resource dedicated to the specific preamble. This means that both the preamble and the Msg3 face contention. However, contention resolution in this case means that either both preamble and Msg 3 are sent without collision or both collide. The 2-step RA procedure is depicted in FIG. **2**.

[0034] Upon successful reception msgA, the network node will respond with a msgB. The msgB may be either a "successRAR", "fallbackRAR or "Back off". The content of msgB has been agreed as seen below. It is noted in particular that fallbackRAR provides a grant for a Msg3 PUSCH that identifies resources in which the WD should transmit the PUSCH, as well as other information.

[0035] Note: The notations "msgA" and "MsgA" are used interchangeably herein to denote message A. Similarly, the notations "msgB" and "MsgB" are used interchangeably herein to denote message B.

[0036] The possibility of replacing the 4-step message exchange by a 2-step message exchange would lead to reduced RA latency. On the other hand, the 2-step RA will consume more resources since it uses contention-based transmission of the data. This means that the resources that are configured for the data transmission may often be unused.

[0037] If both the 4-step and 2-step RA are configured in a cell on shared PRACH resources (and for the WD), the WD will choose its preamble from one set if it wants to do a 4-step RA, and from another set if it wants to do a 2-step RA. Hence, a preamble partition is created to distinguish between 4-step and 2-step RA when shared PRACH resources are used. Alternatively, the PRACH configurations are different for the 2-step and 4-step RA procedure. In this case, it may be deduced from where the preamble transmission is performed, whether the WD is performing a 2-step procedure or a 4-step procedure.

[0038] In the 3GPP Rel-16 2-step RA type procedure, WDs are informed of the potential time-frequency resources where they may transmit MsgA PRACH and MsgA PUSCH via higher layer signaling from the network node. PRACH is transmitted in periodically recurring RACH occasions ('ROs'), while PUSCH is transmitted in periodically recurring PUSCH occasions ('POs'). PUSCH occasions are described in MsgA PUSCH configurations provided by higher layer signaling. Each MsgA PUSCH configuration defines a starting time of the PUSCH occasions that is measured from the start of a corresponding RACH occasion. Multiple PUSCH occasions may be multiplexed in time and frequency in a MsgA PUSCH configuration, where POs in an orthogonal frequency division multiplexed (OFDM) symbol occupy a given number of physical resource blocks (PRBs) and are adjacent in frequency, and where POs occupy 'L' contiguous OFDM symbols. POs multiplexed in time in a MsgA PUSCH configuration may be separated by a configured gap that is 'G' symbols long. The start of the first occupied OFDM symbol in a PUSCH slot is indicated via a start and length indicator value ('SLIV'). The MsgA PUSCH configuration may comprise multiple contiguous PUSCH slots, each slot containing the same number of POs. The start of the first physical resource block (PRB) relative to the first PRB in a bandwidth part (BWP) is also given by the MsgA PUSCH configuration. Moreover, the modulation and coding scheme (MCS) for MsgA PUSCH is also given by the MsgA PUSCH configuration.
[0039] Each PRACH preamble maps to a PUSCH occasion and a demodulation reference signal (DMRS) port and/or to a DMRS port-scrambling sequence combination according to a procedure given in 3GPP standards such as in, for example, 3GPP Technical Specification (TS) 38.213. This mapping allows a network node to uniquely determine the location of the associated PUSCH in time and frequency as well as the DMRS port and/or scrambling sequence from the preamble selected by the WD.
[0040] The PRACH preambles also map to associated SSBs. The SSB to preamble association combined with the preamble to PUSCH association allow a PO to be associated with a RACH preamble. This indirect preamble-to-PUSCH mapping may be used to allow a network node using analog beamforming to receive a MsgA PUSCH with the same beam that it uses to receive the MsgA RACH preamble.
[0041] In NR, since the network node will control the UL transmission to avoid the collision among WDs, the network node will assign the dedicated UL resources in frequency and time domain. One exception is the case when WD will make an initial access to the network node from IDLE/INACTIVE states. Random access is the procedure used when the WD initiates a connection with the network node. 3GPP has specified two types of random access procedures: 4-step RA type and 2-step RA type and these are described in detail in clause 2.1.3 of 3GPP TS 38.213.
[0042] Regardless of whether a 4-step RA procedure or a 2-step RA procedure is used, the WD must transmit a random access preamble using PRACH at the beginning of random access attempts. Since the network node does not know when the WD initiates the random access, the network node allocates the UL resources for PRACH periodically at a periodicity called RACH periodicity. RACH periodicity is configurable, e.g., 10 ms. 20 ms, 40 ms, 80 ms, and 160 ms.
[0043] FIG. **3** illustrates the relation between a RACH occasion and a paging period (or DRX cycle).
[0044] Connected mode DRX (C-DRX) is configured not to monitor the PDCCH every slot in CONNECTED mode to help WD save battery power. When C-DRX is configured, the WD is required to awake to monitor the PDCCH periodically. The WD can sleep (e.g., turn off some baseband circuits or clock down the baseband circuit) for the period the WD is not required to monitor the PDCCH. But the WD can awake and send the Scheduling Request during the sleep period if the WD has UL data scheduled from the upper layer.
[0045] Every time after the WD receives the PDCCH, the WD starts the inactivity timer (drx-InActivityTimer, e.g., 10 ms). This timer extends the monitoring period during which the WD needs to wake and monitor the PDCCH until the inactivity timer is expired. After the inactivity

timer is expired, the WD can go to the short DRX cycle where the WD wakes and monitor the PDCCH every short DRX cycle (drx-ShortCycle, e.g., 10 ms). Every short DRX cycle, the WD awakes and monitors the PDCCH during 'on duration' given by drx-onDurationTimer, e.g., 2 ms. The WD continues short DRX activity during the period that the short DRX cycle timer is running. After the short DRX cycle timer is expired, the WD can go to the long DRX cycle, where the WD awakes and monitors the PDCCH every long DRX cycle (drx-LongCycle, e.g., 320 ms). Every short DRX cycle, the WD awakes and monitors the PDCCH during 'on duration' given by drx-onDurationTimer, e.g., 10 ms.

[0046] When the WD is in sleep mode, the WD does not receive any signals and uses its internal clock to schedule when the WD awakes for the next DRX cycle. Since the clock in the WD is not as accurate as the clock in the network node, the WD needs to re-synchronize to the network node in advance by receiving the common downlink signal such as SSB or TRS. Moreover, the WD may move to another location or change its direction during the sleep mode. This results in the changes on received signal level and hence, the WD may need to adjust the gain of the receiver's amplifier (i.e., low-noise amplifier, LNA) by using an automatic gain control (AGC) algorithm. The WD needs to receive SSB or TRS to run the AGC algorithm.

[0047] The WD can use the SS/PBCH block for time/frequency tracking and AGC. In NR, the SSB consists of primary and secondary synchronization signals (PSS and SSS) and the physical broadcast channel (PBCH). The WD may use, e.g., synchronization signals to re-synchronize to the network node and adjust the gain of the LNA of the receiver of the WD. The network node transmits SS/PBCH periodically, e.g., every 5 ms, 10 ms, 20 ms, 40 ms, 80 ms, and 160 ms. The periodicity is configured via radio resource control (RRC) parameters. However, a default periodicity of 20 ms is assumed during initial cell search. To support initial access and beam management, NR supports an SS burst set which consists of multiple SS blocks confined within a 5 ms window.

[0048] Another downlink (DL) reference signal (RS) that the WD can use for time/frequency tracking and AGC is the channel state information reference signal (CSI-RS) for tracking. CRS-RS for tracking is also referred to as the tracking reference signal (TRS). The network node transmits a TRS periodically, e.g., 10 ms, 20 ms, 40 ms or 80 ms.

[0049] There are several configured uplink (UL) resources for the WDs in CONNECTED mode: PUCCH, sounding reference signals (SRS), and Uplink configured transmission (CG-PUSCH):

[0050] PUCCH: PUCCH is allocated to transmit Scheduling Request (SR). When the WD requires UL resources for new UL transmission in the connected mode, the WD sends a SR using the configured PUCCH. The SR may be transmitted even if the WD is asleep in DRX. The SR is configured periodically, e.g., every 160 slots; [0051] SRS: A sounding reference signal (SRS) is the UL reference signal transmitted by the WD. The network node uses SRS to measure the UL propagation channel condition. The network node can schedule aperiodic SRS transmission (i.e., one shot transmission), semi-persistent SRS transmission (transmit several SRS times periodically), and periodic SRS transmission. For the semi-persistent or periodic SRS transmission, the network node can configure the WD to transmit SRS e.g., every 160 slots; [0052] CG-PUSCH: CG-PUSCH enables UL data transmission by pre-allocating resources to avoid SR and scheduling grant procedure before the UL data transmission. The main purpose of CG-PUSCH is for low-latency UL data transmission. Since the network node does not know when the WD has UL data to transmit, the network node can configure the preconfigured UL grant periodically, e.g., every 10 slots.

[0053] FIG. **4** illustrates the relationship between the configured UL resources and the On duration in C-DRX. This example also shows the SSB/TRS transmission.

[0054] 3GPP NR defines three duplex schemes: Time Division Duplex (TDD), Full-duplex Frequency Division Duplex (FD-FDD) and Half-duplex Frequency Division Duplex (HD-FDD). In TDD operation, the WD and the network node use a single frequency band and switch between uplink and downlink transmission in the time domain. On the other hand, FDD uses two paired

frequency bands, and one frequency is used for uplink and the other frequency is used for downlink transmission. A difference between full-duplex and half-duplex is that for FD-FDD operation, the WD can transmit and receive data simultaneously, while for HD-FDD operation, the WD switches between UL transmission and DL transmission in the time domain in the same fashion as for TDD. However, the WD uses different frequencies for UL and DL transmission. There is a difference in the behavior of the network node between HD-FDD and TDD operation, but the network node behaves the same for both the HD-FDD-configured WD and the FD-FDD-configured WD.
[0055] For the network node operating in FDD bands, the network node handles both HD-FDD WDs and FD-FDD WDs. The network node therefore schedules the SSB and the TRS, targeting both HD-FDD WDs and FD-FDD WDs. The WD should receive these channel signals for Cell ID detection, time/frequency tracking, and AGC regardless of regardless of full-duplex or half-duplex.
[0056] For a RedCap device, the support of FD-FDD is optional, i.e., it is not required to receive in the downlink frequency while transmitting in the uplink frequency, and vice versa. HD-FDD obviates the need for duplex filters. Instead, a switch may be used to select the transmitter or receiver to connect to the antenna. As a switch is less expensive than multiple duplexers, cost savings are achieved.
[0057] An FD-FDD WD requires two oscillators. One oscillator is used for an UL frequency and another oscillator is used for a DL frequency. In contrast, a HD-FDD WD may have only one oscillator, and the WD is configured to switch the frequency in time. This means that when the WD needs to receive DL signals, the WD tunes the oscillator frequency to a DL frequency and when the WD needs to transmit UL signals, the WD tunes the oscillator frequency to an UL frequency. An HD-FDD WD with a single oscillator requires a switching period or transmission period from DL frequency to UL frequency, T.sub.DL-to-UL, and UL frequency to DL frequency, T.sub.UL-to-DL. One example of transition time is T.sub.DL-to-UL=T.sub.UL-to-DL=1 ms.
[0058] In NR in RRC_INACTIVE state, a WD with infrequent periodic and/or aperiodic data can transmit a small amount of data, which is called small data transmission (SΔT). Small data transmission (SΔT) is therefore a procedure to transmit UL data by the WD in RRC_INACTIVE state. SΔT is performed with either random access (using RACH-based SΔT) or configured grant (CG) (using Configured Grant (CG) based SΔT). If the WD uses 4-step RA type for SΔT procedure, then the WD transmits the UL data in the Msg3. If the WD uses 2-step RA type for SΔT procedure, then the WD transmits UL data in the MsgA.
[0059] CG PUSCH resources are the PUSCH resources configured in advance for the WD. When there is uplink data available in the WD's buffer, it can immediately start uplink transmission using the pre-configured PUSCH resources without waiting for an UL grant from the network node, thus reducing the latency. NR supports CG type 1 PUSCH transmission and CG type 2 PUSCH transmission. For both types, the PUSCH resources (time and frequency allocation, periodicity, etc.) are preconfigured via dedicated RRC signaling. The CG type 1 PUSCH transmission is activated/deactivated by RRC signaling, while the CG type 2 PUSCH transmission is activated/deactivated by an UL grant using downlink control information (DCI) signaling. An association between CG resources and SSBs is configured for CG-based SΔT.
[0060] Upon arrival of the data in the WD buffer, the WD may decide whether to use the SΔT mechanism or the legacy mechanism (e.g., by sending the RRCResumeRequest) to transmit the data based on comparison between the reference signal received power (RSRP) of a configured RS and an RSRP threshold (e.g., RSRP-threshold-STD). For example, an SΔT mechanism is selected if the RSRP is above the RSRP-threshold-STD; otherwise a legacy mechanism is used. The WD selects the CG-SΔT resource for transmission based on comparison between the RSRP of configured RS and an the RSRP threshold. For example, CG-SΔT resources associated with or corresponding to a RS (e.g., SSB) whose RSRP is above an RSRP threshold (e.g., RSRP-thresholdCG) are selected by the WD for data transmission
[0061] Even if the WD is operated in half-duplex FDD (HD-FDD) mode, the network node (e.g.,

gNB) still operates in full-duplex FDD (FD-FDD). The network node needs to configure common DL resources for both full-duplex WDs and half-duplex WDs, e.g., SSB/TRS/SIB/Paging. There are also common UL resources which are scheduled for both full-duplex WDs and half-duplex WDs, e.g., random access occasion (RO) and PUCCH transmission.

[0062] Sometimes, the network node cannot avoid the case that DL signal reception and UL transmission (e.g., paging reception and PUCCH transmission) overlap with each other fully or partly in time. The WD, after waking up from a period of inactivity (e.g., DRX OFF, eDRX), has to perform resynchronization (e.g., time and/or frequency tracking, AGC, automatic frequency control (AFC)) towards the serving cell to be able to receive DL channels/signals or transmit UL channels/signals). Different types of DL reference signals may be used for this purpose. At the same time, in NR, the PO is associated with SSB index. The WD can only monitor the paging based on the best SSB in terms of its received signal at the WD, e.g., SSB which gives largest signal strength measurement at the WD (e.g., SSB with largest RSRP). However, since the HD-FDD WD cannot receive and transmit simultaneously, the measurement occasions may be quite limited compared to a FD-FDD WD. The WD behavior in this overlapping scenario is currently undefined.

SUMMARY

[0063] Some embodiments advantageously provide methods, systems, and apparatuses for proactive (SSB)/(TRS) reception procedures for half-duplex operation.

[0064] Some embodiments are applicable to a scenario with a WD (e.g., WD1) operating in HD-FDD mode served by a cell (cell1) managed by a network (e.g., NW1), and there is an overlap or conflict between UL transmission and DL reception in time. One example of UL transmission is random access transmission, and one example of DL reception is reception of a DL reference signal (RS), e.g., SSB.

[0065] In some embodiments, a WD configured in HD-FDD mode and served by a first cell (cell1), and configured to operate a second signal (S**2**) in a radio resource (Rr) starting at a time instance, T**2**, determines whether a first signal reception (FSR) condition is met by the WD, and determines whether the WD operates S**2** in Rr based on whether the FSR is met by the WD.

[0066] FSR is determined by a rule, which may be pre-defined or configured by the network node. In one example of the rule, the WD meets FSR provided that the WD can receive at least N number of a first signal (S**1**) or at least N number of S**1** is available at the WD during a time period (ΔT) before T**2** or between time instances T**1** and T**2**; where $\Delta T \Delta T = T2 - T1$ and $T1 < T2$, e.g., T**1** is the time instance occurring before T**2**.

[0067] If the WD fulfills at least one FSR condition, then the WD is expected to operate or it can operate or is required to operate S**2** in the resource Rr. Otherwise, the WD is not expected to operate or is not required to operate or may not operate S**2** in the resource Rr. In the latter case, the WD may further postpone or discard the operation of S**2**.

[0068] Examples of operating a signal may include transmitting a signal, receiving a signal or both transmitting and receiving a signal.

[0069] Examples of S**1** are reference signals (RS) e.g., PSS, SSS, SS/PBCH block (SSB), CSI-RS, DMRS, PRS, etc.

[0070] Examples of DL S**2** signals include paging, system information (S**1**) (e.g., SIB1, SIB2, etc.).

[0071] Examples of UL S**2** signals include random access (RA), SRS, msgA, msg1, etc.

[0072] Some embodiments with S**2** as a paging signal may include one or more of the following:

[0073] In some embodiments, during the time period ΔTΔT before a paging monitoring occasion (PO), the HD-FDD WD prioritizes DL reception of at least N number of RS (e.g., SSB reception, TRS reception) over UL transmission (e.g., random access or any other UL transmission). This allows the WD to perform resynchronization (time/frequency tracking) towards cell1 to be able to receive paging messages later in time in a PO starting from T**2**, where T**2**>T**1**. In this case, the WD is required to fulfill the paging requirements, i.e., does not miss the paging reception assuming sufficient radio conditions. Otherwise, DL measurement occasions during ΔTΔT cannot be guaranteed. Then the WD may be allowed to miss the paging reception in the PO starting from T**2**. In one example, N=1; [0074] During the period ΔTΔT before the DL signal reception (e.g., paging) for the WD configured with DRX, the HD-FDD WD prioritizes reception of at least N number of SSBs over random access or any other UL transmission. Optionally, the WD prioritizes TRS reception over random access or any other UL transmission. In one example, N=1.

[0075] Some embodiments with S**2** as RA signal may include one or more of the following: [0076] In some embodiments, during the time period ΔT before a random access occasion (RO) in a target cell, the HD-FDD WD prioritizes DL reception of at least N number of RS (e.g., SSB reception, TRS reception) over UL transmission (e.g., random access or any other UL transmission) to allow the WD to perform resynchronization (time/frequency tracking) towards the target cell to be able to transmit later in time, the RO starting from T**2**, where T**2**>T**1**. In this case, the WD may be required to fulfill the RA requirements, i.e., so that it does not miss the RA transmission in the Rr starting from T**2**. Otherwise, i.e., if DL measurement occasions during ΔT cannot be guaranteed, then the WD may be allowed to miss or drop the RA transmission in the RO starting from T**2**. In one example, N=1.

[0077] According to one aspect, a wireless device, WD, configured to communicate with a network node in a half-duplex frequency division duplex, HD-FDD, mode is provided. The WD includes processing circuitry configured to determine whether a first signal reception, FSR, condition is met, the FSR condition including one of receipt and availability of at least N first signals during a time interval ΔT ending at a time T**2**, N being an integer greater than zero. The processing circuitry is further configured to, provided that the FSR condition is met, operate a second signal on a radio resource at the time T**2**.

[0078] According to this aspect, in some embodiments, the processing circuitry is further configured to prioritize downlink reception over uplink transmission during the time interval ΔT. In some embodiments, the processing circuitry is further configured to prioritize reception of a reference signal over transmission of a random access. In some embodiments, the second signal is a paging signal and the resource is a paging resource. In some embodiments, when the second signal is a downlink signal received by the WD, the second signal includes at least one of a paging signal and system information. In some embodiments, when the second signal is an uplink signal transmitted by the WD, the second signal includes at least one of a random access signal, a sounding reference signal, an msgA, an msg1 and an uplink transmission using configured grant-small data transmission (CG-SDT). In some embodiments, the second signal includes a paging signal and the processing circuitry is further configured to prioritize downlink reception of at least N first reference signals to enable synchronization between the WD and the network node prior to a paging occasion that starts at the time T**2**. In some embodiments, the FSR condition includes receiving at least N number of first signals during the time interval ΔT that have a bandwidth exceeding a first threshold. In some embodiments, the FSR condition includes receiving at least N2 first signals during the time interval ΔT that have a bandwidth that falls below a second threshold, N2 being an integer greater than 1. In some embodiments, the processing circuitry is further configured to select between two step random access and four-step random access when the FSR condition is met and the second signal is a random access signal. In some embodiments, the processing circuitry is further configured to refrain from selecting between two step random access and four-step random access when the FSR condition is not met. In some embodiments, the processing circuitry is further configured to perform a random access transmission in a physical random access channel, PRACH, occasion when the FSR condition is met. In some embodiments, when the FSR condition is not met, the processing circuitry is further configured to one of postpone, defer and delay operating the second signal. In some embodiments, when the FSR condition is not met, the processing circuitry is further configured to one of postpone, defer and delay operating the second signal until the FSR condition is met. In some embodiments, when the

FSR condition is not met, the processing circuitry is further configured to one of discard and cancel operating the second signal. In some embodiments, when the FSR condition is not met, the processing circuitry is further configured to one of discard and cancel operating the second signal after M failed attempts to operate the second signal, M being an integer greater than zero. In some embodiments, when the WD is in a low-activity radio resource control, RRC state, the processing circuitry is further configured to re-synchronize with the network node and to perform automatic gain control during the time interval ΔT. In some embodiments, ΔT is determined based at least in part on one of a synchronization status of the WD, a discontinuous reception time, and a reference signal transmission periodicity. In some embodiments, operating the second signal includes receiving one of a paging signal, performing a random access procedure, and transmitting a small data transmission, SDT.

[0079] According to another aspect, a method in a wireless device, WD, configured to communicate with a network node in a half-duplex frequency division duplex, HD-FDD, mode is provided. The method includes determining whether a first signal reception, FSR, condition is met, the FSR condition including one of receipt and availability of at least N first signals during a time interval ΔT ending at a time T**2**, N being an integer greater than zero. The method also includes, provided that the FSR condition is met, operating a second signal on a radio resource at the time T**2**.

[0080] According to this aspect, in some embodiments, the method also includes prioritizing downlink reception over uplink transmission during the time interval ΔT. In some embodiments, the method also includes prioritizing reception of a reference signal over transmission of a random access. In some embodiments, the second signal is a paging signal and the resource is a paging resource. In some embodiments, when the second signal is a downlink signal received by the WD, the second signal includes at least one of a paging signal and system information. In some embodiments, when the second signal is an uplink signal transmitted by the WD, the second signal includes at least one of a random access signal, a sounding reference signal, an msgA, an msg1 and an uplink transmission using configured grant-small data transmission (CG-SDT). In some embodiments, the method includes, when the second signal includes a paging signal, prioritizing downlink reception of at least N first reference signals to enable synchronization between the WD and the network node prior to a paging occasion that starts at the time T**2**. In some embodiments, the FSR condition includes receiving at least N1 number of first signals during the time interval ΔT that have a bandwidth exceeding a first threshold. In some embodiments, the FSR condition includes receiving at least N2 first signals during the time interval ΔT that have a bandwidth that falls below a second threshold, N2 being an integer greater than 1. In some embodiments, the method also includes selecting between two step random access and four-step random access when the FSR condition is met and the second signal is a random access signal. In some embodiments, the method includes refraining from selecting between two step random access and four-step random access when the FSR condition is not met. In some embodiments, the method includes performing a random access transmission in a physical random access channel, PRACH, occasion when the FSR condition is met. In some embodiments, the method includes, when the FSR condition is not met, one of postponing, deferring and delaying operating the second signal. In some embodiments, the method includes, when the FSR condition is not met, one of postponing, deferring and delaying operating the second signal until the FSR condition is met. In some embodiments, the method includes, when the FSR condition is not met, one of discarding and canceling operating the second signal. In some embodiments, the method includes, when the FSR condition is not met, one of discarding and canceling operating the second signal after M failed attempts to operate the second signal, M being an integer greater than zero. In some embodiments, when the WD is in a low-activity radio resource control, RRC state, configuring the WD to re-synchronize with the network node and to perform automatic gain control during the time interval ΔT. In some embodiments, ΔT is determined based at least in part on one of a synchronization

status of the WD, a discontinuous reception time, and a reference signal transmission periodicity. In some embodiments, operating the second signal includes receiving one of a paging signal, performing a random access procedure, and transmitting a small data transmission, SDT.
[0081] According to another aspect, a network node configured to communicate with a wireless device, WD, in a half-duplex frequency division duplex, HD-FDD, mode is provided. The network node includes a radio interface configured to transmit to the WD at least N first signals during the time interval ΔT ending at a time T**2**, N being an integer greater than zero. The network node includes processing circuitry in communication with the radio interface and configured to schedule uplink resources for uplink transmissions by the WD after the time T**2**, the uplink transmissions being responsive to one of receipt and availability of the at least N first signals during the time interval ΔT.
[0082] According to this aspect, in some embodiments, the processing circuitry is further configured to schedule at least one of a two-step random access and a four-step random access while avoiding overlapping synchronization signal resources and uplink resources in the time domain. In some embodiments, the time interval ΔT is greater than a synchronization signal periodicity plus a first switching time from uplink receipt to downlink transmission. In some embodiments, the processing circuitry is further configured to schedule the uplink resources during a time period between: a start of a synchronization signal minus the first switching time; and an end of the synchronization signal plus a second switching time from downlink transmission to uplink receipt. In some embodiments, the at least N first signals are synchronization signal and physical broadcast channel signal blocks, SSBs.
[0083] According to yet another aspect, a method in a network node configured to communicate with a wireless device, WD, in a half-duplex frequency division duplex, HD-FDD, mode is provided. The method includes transmitting to the WD at least N first signals during the time interval ΔT ending at a time T**2**, N being an integer greater than zero. The method includes scheduling uplink resources for uplink transmissions by the WD after the time T**2**, the uplink transmissions being responsive to one of receipt and availability of the at least N first signals during the time interval ΔT.
[0084] According to this aspect, in some embodiments, the method includes scheduling at least one of a two-step random access and a four-step random access while avoiding overlapping synchronization signal resources and uplink resources in the time domain. In some embodiments, the time interval ΔT is greater than a synchronization signal periodicity plus a first switching time from uplink receipt to downlink transmission. In some embodiments, the method includes scheduling the uplink resources during a time period between: a start of a synchronization signal minus the first switching time; and an end of the synchronization signal plus a second switching time from downlink transmission to uplink receipt. In some embodiments, the at least N first signals are synchronization signal and physical broadcast channel signal blocks, SSBs.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0085] A more complete understanding of the present embodiments, and the attendant advantages and features thereof, will be more readily understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein:
[0086] FIG. **1** illustrates a 4 step RA procedure;
[0087] FIG. **2** illustrates a 2 step RA procedure;
[0088] FIG. **3** is an example of DL/UL resources for a WD in IDLE/INACTIVE mode;
[0089] FIG. **4** is an example of DL/UL resources for a WD in CONNECTED mode DRX;
[0090] FIG. **5** is a schematic diagram of an example network architecture illustrating a

communication system connected via an intermediate network to a host computer according to the principles in the present disclosure;

[0091] FIG. **6** is a block diagram of a host computer communicating via a network node with a wireless device over an at least partially wireless connection according to some embodiments of the present disclosure;

[0092] FIG. **7** is a flowchart illustrating example methods implemented in a communication system including a host computer, a network node and a wireless device for executing a client application at a wireless device according to some embodiments of the present disclosure;

[0093] FIG. **8** is a flowchart illustrating example methods implemented in a communication system including a host computer, a network node and a wireless device for receiving user data at a wireless device according to some embodiments of the present disclosure;

[0094] FIG. **9** is a flowchart illustrating example methods implemented in a communication system including a host computer, a network node and a wireless device for receiving user data from the wireless device at a host computer according to some embodiments of the present disclosure;

[0095] FIG. **10** is a flowchart illustrating example methods implemented in a communication system including a host computer, a network node and a wireless device for receiving user data at a host computer according to some embodiments of the present disclosure;

[0096] FIG. **11** is a flowchart of an example process in a wireless device for proactive (SSB)/(TRS) reception procedures for half-duplex operation;

[0097] FIG. **12** is a flowchart of another example process in a wireless device for proactive (SSB)/(TRS) reception procedures for half-duplex operation;

[0098] FIG. **13** is a flowchart of an example process in a network node for proactive (SSB)/(TRS) reception procedures for half-duplex operation;

[0099] FIG. **14** is an example of the WD operating N number of signals;

[0100] FIG. **15** illustrates an example where an SSB is scheduled with the periodicity T.sub.SSB;

[0101] FIG. **16** illustrates an example for DL measurement occasions;

[0102] FIG. **17** illustrates an example when the WD uses an SSB;

[0103] FIG. **18** illustrates an example where an SSB is scheduled with the periodicity T.sub.SSB;

[0104] FIG. **19** is an example of the SSB measurement prioritization before random access; and

[0105] FIG. **20** is an example of UL transmission after SSB measurements.

DETAILED DESCRIPTION

[0106] Before describing in detail example embodiments, it is noted that the embodiments reside primarily in combinations of apparatus components and processing steps related to proactive (SSB)/(TRS) reception procedures for half-duplex operation. Accordingly, components have been represented where appropriate by conventional symbols in the drawings, showing only those specific details that are pertinent to understanding the embodiments so as not to obscure the disclosure with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein. Like numbers refer to like elements throughout the description.

[0107] As used herein, relational terms, such as “first” and “second,” “top” and “bottom,” and the like, may be used solely to distinguish one entity or element from another entity or element without necessarily requiring or implying any physical or logical relationship or order between such entities or elements. The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the concepts described herein. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,” “comprising,” “includes” and/or “including” when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0108] In embodiments described herein, the joining term, “in communication with” and the like, may be used to indicate electrical or data communication, which may be accomplished by physical contact, induction, electromagnetic radiation, radio signaling, infrared signaling or optical signaling, for example. One having ordinary skill in the art will appreciate that multiple components may interoperate and modifications and variations are possible of achieving the electrical and data communication.

[0109] In some embodiments described herein, the term “coupled,” “connected,” and the like, may be used herein to indicate a connection, although not necessarily directly, and may include wired and/or wireless connections.

[0110] The term “network node” used herein may be any kind of network node comprised in a radio network which may further comprise any of base station (BS), radio base station, base transceiver station (BTS), base station controller (BSC), radio network controller (RNC), g Node B (gNB), evolved Node B (eNB or eNodeB), Node B, multi-standard radio (MSR) radio node such as MSR BS, multi-cell/multicast coordination entity (MCE), integrated access and backhaul (IAB) node, relay node, donor node controlling relay, radio access point (AP), transmission points, transmission nodes, Remote Radio Unit (RRU) Remote Radio Head (RRH), a core network node (e.g., mobile management entity (MME), self-organizing network (SON) node, a coordinating node, positioning node, MAT node, etc.), an external node (e.g., 3rd party node, a node external to the current network), nodes in distributed antenna system (DAS), a spectrum access system (SAS) node, an element management system (EMS), etc. The network node may also comprise test equipment. The term “radio node” used herein may be used to also denote a wireless device (WD) such as a wireless device (WD) or a radio network node.

[0111] In some embodiments, the non-limiting terms wireless device (WD) or a user equipment (UE) are used interchangeably. The WD herein may be any type of wireless device capable of communicating with a network node or another WD over radio signals, such as wireless device (WD). The WD may also be a radio communication device, target device, device to device (D2D) WD, machine type WD or WD capable of machine to machine communication (M2M), low-cost and/or low-complexity WD, a sensor equipped with WD, Tablet, mobile terminals, smart phone, laptop embedded equipped (LEE), laptop mounted equipment (LME), USB dongles, Customer Premises Equipment (CPE), an Internet of Things (IoT) device, or a Narrowband IoT (NB-IOT) device, etc.

[0112] Also, in some embodiments the generic term “radio network node” is used. It may be any kind of a radio network node which may comprise any of base station, radio base station, base transceiver station, base station controller, network controller, RNC, evolved Node B (eNB), Node B, gNB, Multi-cell/multicast Coordination Entity (MCE), IAB node, relay node, access point, radio access point, Remote Radio Unit (RRU) Remote Radio Head (RRH).

[0113] Note that although terminology from one particular wireless system, such as, for example, 3GPP LTE and/or New Radio (NR), may be used in this disclosure, this should not be seen as limiting the scope of the disclosure to only the aforementioned system. Other wireless systems, including without limitation Wide Band Code Division Multiple Access (WCDMA), Worldwide Interoperability for Microwave Access (WiMax), Ultra Mobile Broadband (UMB) and Global System for Mobile Communications (GSM), may also benefit from exploiting the ideas covered within this disclosure.

[0114] Note further, that functions described herein as being performed by a wireless device or a network node may be distributed over a plurality of wireless devices and/or network nodes. In other words, it is contemplated that the functions of the network node and wireless device described herein are not limited to performance by a single physical device and, in fact, may be distributed among several physical devices.

[0115] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. It will be further understood that terms used herein should be interpreted as having a meaning that is consistent with their meaning in the context of this specification and the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0116] Some embodiments provide proactive (SSB)/(TRS) reception procedures for half-duplex operation.

[0117] Referring again to the drawing figures, in which like elements are referred to by like reference numerals, there is shown in FIG. **5** a schematic diagram of a communication system **10**, according to an embodiment, such as a 3GPP-type cellular network that may support standards such as LTE and/or NR (5G), which comprises an access network **12**, such as a radio access network, and a core network **14**. The access network **12** comprises a plurality of network nodes **16***a*, **16***b*, **16***c* (referred to collectively as network nodes **16**), such as NBs, eNBs, gNBs or other types of wireless access points, each defining a corresponding coverage area **18***a*, **18***b*, **18***c* (referred to collectively as coverage areas **18**). Each network node **16***a*, **16***b*, **16***c* is connectable to the core network **14** over a wired or wireless connection **20**. A first wireless device (WD) **22***a* located in coverage area **18***a* is configured to wirelessly connect to, or be paged by, the corresponding network node **16***a*. A second WD **22***b* in coverage area **18***b* is wirelessly connectable to the corresponding network node **16***b*. While a plurality of WDs **22***a*, **22***b* (collectively referred to as wireless devices **22**) are illustrated in this example, the disclosed embodiments are equally applicable to a situation where a sole WD is in the coverage area or where a sole WD is connecting to the corresponding network node **16**. Note that although only two WDs **22** and three network nodes **16** are shown for convenience, the communication system may include many more WDs **22** and network nodes **16**.

[0118] Also, it is contemplated that a WD **22** may be in simultaneous communication and/or configured to separately communicate with more than one network node **16** and more than one type of network node **16**. For example, a WD **22** can have dual connectivity with a network node **16** that supports LTE and the same or a different network node **16** that supports NR. As an example, WD **22** may be in communication with an eNB for LTE/E-UTRAN and a gNB for NR/NG-RAN.

[0119] The communication system **10** may itself be connected to a host computer **24**, which may be embodied in the hardware and/or software of a standalone server, a cloud-implemented server, a distributed server or as processing resources in a server farm. The host computer **24** may be under the ownership or control of a service provider, or may be operated by the service provider or on behalf of the service provider. The connections **26**, **28** between the communication system **10** and the host computer **24** may extend directly from the core network **14** to the host computer **24** or may extend via an optional intermediate network **30**. The intermediate network **30** may be one of, or a combination of more than one of, a public, private or hosted network. The intermediate network **30**, if any, may be a backbone network or the Internet. In some embodiments, the intermediate network **30** may comprise two or more sub-networks (not shown).

[0120] The communication system of FIG. **5** as a whole enables connectivity between one of the connected WDs **22***a*, **22***b* and the host computer **24**. The connectivity may be described as an over-the-top (OTT) connection. The host computer **24** and the connected WDs **22***a*, **22***b* are configured to communicate data and/or signaling via the OTT connection, using the access network **12**, the core network **14**, any intermediate network **30** and possible further infrastructure (not shown) as intermediaries. The OTT connection may be transparent in the sense that at least some of the participating communication devices through which the OTT connection passes are unaware of routing of uplink and downlink communications. For example, a network node **16** may not or need not be informed about the past routing of an incoming downlink communication with data originating from a host computer **24** to be forwarded (e.g., handed over) to a connected WD **22***a*. Similarly, the network node **16** need not be aware of the future routing of an outgoing uplink communication originating from the WD **22***a* towards the host computer **24**.

[0121] A network node is configured to include a scheduling unit **32** which is configured to schedule uplink resources for uplink transmissions by the WD after the time T**2**, the uplink transmissions being responsive to one of receipt and availability of the at least N first signals during the time interval ΔT. A wireless device **22** is configured to include an FSR unit **34** configured to determine whether a first signal reception, FSR, condition is met, the FSR condition including one of receipt and availability of at least N first signals during a time interval ΔT ending at a time T**2**, N being an integer greater than zero.

[0122] Example implementations, in accordance with an embodiment, of the WD **22**, network node **16** and host computer **24** discussed in the preceding paragraphs will now be described with reference to FIG. **6**. In a communication system **10**, a host computer **24** comprises hardware (HW) **38** including a communication interface **40** configured to set up and maintain a wired or wireless connection with an interface of a different communication device of the communication system **10**. The host computer **24** further comprises processing circuitry **42**, which may have storage and/or processing capabilities. The processing circuitry **42** may include a processor **44** and memory **46**. In particular, in addition to or instead of a processor, such as a central processing unit, and memory, the processing circuitry **42** may comprise integrated circuitry for processing and/or control, e.g., one or more processors and/or processor cores and/or FPGAs (Field Programmable Gate Array) and/or ASICs (Application Specific Integrated Circuitry) adapted to execute instructions. The processor **44** may be configured to access (e.g., write to and/or read from) memory **46**, which may comprise any kind of volatile and/or nonvolatile memory, e.g., cache and/or buffer memory and/or RAM (Random Access Memory) and/or ROM (Read-Only Memory) and/or optical memory and/or EPROM (Erasable Programmable Read-Only Memory).

[0123] Processing circuitry **42** may be configured to control any of the methods and/or processes described herein and/or to cause such methods, and/or processes to be performed, e.g., by host computer **24**. Processor **44** corresponds to one or more processors **44** for performing host computer **24** functions described herein. The host computer **24** includes memory **46** that is configured to store data, programmatic software code and/or other information described herein. In some embodiments, the software **48** and/or the host application **50** may include instructions that, when executed by the processor **44** and/or processing circuitry **42**, causes the processor **44** and/or processing circuitry **42** to perform the processes described herein with respect to host computer **24**. The instructions may be software associated with the host computer **24**.

[0124] The software **48** may be executable by the processing circuitry **42**. The software **48** includes a host application **50**. The host application **50** may be operable to provide a service to a remote user, such as a WD **22** connecting via an OTT connection **52** terminating at the WD **22** and the host computer **24**. In providing the service to the remote user, the host application **50** may provide user data which is transmitted using the OTT connection **52**. The “user data” may be data and information described herein as implementing the described functionality. In one embodiment, the host computer **24** may be configured for providing control and functionality to a service provider and may be operated by the service provider or on behalf of the service provider. The processing circuitry **42** of the host computer **24** may enable the host computer **24** to observe, monitor, control, transmit to and/or receive from the network node **16** and or the wireless device **22**.

[0125] The communication system **10** further includes a network node **16** provided in a communication system **10** and including hardware **58** enabling it to communicate with the host computer **24** and with the WD **22**. The hardware **58** may include a communication interface **60** for setting up and maintaining a wired or wireless connection with an interface of a different communication device of the communication system **10**, as well as a radio interface **62** for setting up and maintaining at least a wireless connection **64** with a WD **22** located in a coverage area **18** served by the network node **16**. The radio interface **62** may be formed as or may include, for example, one or more RF transmitters, one or more RF receivers, and/or one or more RF transceivers. The communication interface **60** may be configured to facilitate a connection **66** to the host computer **24**. The connection **66** may be direct or it may pass through a core network **14** of the communication system **10** and/or through one or more intermediate networks **30** outside the communication system **10**.

[0126] In the embodiment shown, the hardware **58** of the network node **16** further includes processing circuitry **68**. The processing circuitry **68** may include a processor **70** and a memory **72**. In particular, in addition to or instead of a processor, such as a central processing unit, and memory, the processing circuitry **68** may comprise integrated circuitry for processing and/or control, e.g., one or more processors and/or processor cores and/or FPGAs (Field Programmable Gate Array) and/or ASICs (Application Specific Integrated Circuitry) adapted to execute instructions. The processor **70** may be configured to access (e.g., write to and/or read from) the memory **72**, which may comprise any kind of volatile and/or nonvolatile memory, e.g., cache and/or buffer memory and/or RAM (Random Access Memory) and/or ROM (Read-Only Memory) and/or optical memory and/or EPROM (Erasable Programmable Read-Only Memory).

[0127] Thus, the network node **16** further has software **74** stored internally in, for example, memory **72**, or stored in external memory (e.g., database, storage array, network storage device, etc.) accessible by the network node **16** via an external connection. The software **74** may be executable by the processing circuitry **68**. The processing circuitry **68** may be configured to control any of the methods and/or processes described herein and/or to cause such methods, and/or processes to be performed, e.g., by network node **16**. Processor **70** corresponds to one or more processors **70** for performing network node **16** functions described herein. The memory **72** is configured to store data, programmatic software code and/or other information described herein. In some embodiments, the software **74** may include instructions that, when executed by the processor **70** and/or processing circuitry **68**, causes the processor **70** and/or processing circuitry **68** to perform the processes described herein with respect to network node **16**. In some embodiments the processing circuitry **68** and/or processor may include a scheduling unit **32** which is configured to schedule uplink resources for uplink transmissions by the WD after the time T**2**, the uplink transmissions being responsive to one of receipt and availability of the at least N first signals during the time interval ΔT.

[0128] The communication system **10** further includes the WD **22** already referred to. The WD **22** may have hardware **80** that may include a radio interface **82** configured to set up and maintain a wireless connection **64** with a network node **16** serving a coverage area **18** in which the WD **22** is currently located. The radio interface **82** may be formed as or may include, for example, one or more RF transmitters, one or more RF receivers, and/or one or more RF transceivers.

[0129] The hardware **80** of the WD **22** further includes processing circuitry **84**. The processing circuitry **84** may include a processor **86** and memory **88**. In particular, in addition to or instead of a processor, such as a central processing unit, and memory, the processing circuitry **84** may comprise integrated circuitry for processing and/or control, e.g., one or more processors and/or processor cores and/or FPGAs (Field Programmable Gate Array) and/or ASICs (Application Specific Integrated Circuitry) adapted to execute instructions. The processor **86** may be configured to access (e.g., write to and/or read from) memory **88**, which may comprise any kind of volatile and/or nonvolatile memory, e.g., cache and/or buffer memory and/or RAM (Random Access Memory) and/or ROM (Read-Only Memory) and/or optical memory and/or EPROM (Erasable Programmable Read-Only Memory).

[0130] Thus, the WD **22** may further comprise software **90**, which is stored in, for example, memory **88** at the WD **22**, or stored in external memory (e.g., database, storage array, network storage device, etc.) accessible by the WD **22**. The software **90** may be executable by the processing circuitry **84**. The software **90** may include a client application **92**. The client application **92** may be operable to provide a service to a human or non-human user via the WD **22**, with the support of the host computer **24**. In the host computer **24**, an executing host application **50** may communicate with the executing client application **92** via the OTT connection **52** terminating at the WD **22** and the host computer **24**. In providing the service to the user, the client application **92** may receive request data from the host application **50** and provide user data in response to the request data. The OTT connection **52** may transfer both the request data and the user data. The client application **92** may interact with the user to generate the user data that it provides.

[0131] The processing circuitry **84** may be configured to control any of the methods and/or processes described herein and/or to cause such methods, and/or processes to be performed, e.g., by WD **22**. The processor **86** corresponds to one or more processors **86** for performing WD **22** functions described herein. The WD **22** includes memory **88** that is configured to store data, programmatic software code and/or other information described herein. In some embodiments, the software **90** and/or the client application **92** may include instructions that, when executed by the processor **86** and/or processing circuitry **84**, causes the processor **86** and/or processing circuitry **84** to perform the processes described herein with respect to WD **22**. For example, the processing circuitry **84** of the wireless device **22** may include an FSR unit **34** configured to determine whether a first signal reception, FSR, condition is met, the FSR condition including one of receipt and availability of at least N first signals during a time interval ΔT ending at a time T**2**, N being an integer greater than zero.

[0132] In some embodiments, the inner workings of the network node **16**, WD **22**, and host computer **24** may be as shown in FIG. **6** and independently, the surrounding network topology may be that of FIG. **5**.

[0133] In FIG. **6**, the OTT connection **52** has been drawn abstractly to illustrate the communication between the host computer **24** and the wireless device **22** via the network node **16**, without explicit reference to any intermediary devices and the precise routing of messages via these devices. Network infrastructure may determine the routing, which it may be configured to hide from the WD **22** or from the service provider operating the host computer **24**, or both. While the OTT connection **52** is active, the network infrastructure may further take decisions by which it dynamically changes the routing (e.g., on the basis of load balancing consideration or reconfiguration of the network).

[0134] The wireless connection **64** between the WD **22** and the network node **16** is in accordance with the teachings of the embodiments described throughout this disclosure. One or more of the various embodiments improve the performance of OTT services provided to the WD **22** using the OTT connection **52**, in which the wireless connection **64** may form the last segment. More precisely, the teachings of some of these embodiments may improve the data rate, latency, and/or power consumption and thereby provide benefits such as reduced user waiting time, relaxed restriction on file size, better responsiveness, extended battery lifetime, etc.

[0135] In some embodiments, a measurement procedure may be provided for the purpose of monitoring data rate, latency and other factors on which the one or more embodiments improve. There may further be an optional network functionality for reconfiguring the OTT connection **52** between the host computer **24** and WD **22**, in response to variations in the measurement results. The measurement procedure and/or the network functionality for reconfiguring the OTT connection **52** may be implemented in the software **48** of the host computer **24** or in the software **90** of the WD **22**, or both. In embodiments, sensors (not shown) may be deployed in or in association with communication devices through which the OTT connection **52** passes; the sensors may participate in the measurement procedure by supplying values of the monitored quantities exemplified above, or supplying values of other physical quantities from which software **48**, **90** may compute or estimate the monitored quantities. The reconfiguring of the OTT connection **52** may include message format, retransmission settings, preferred routing etc.; the reconfiguring need not affect the network node **16**, and it may be unknown or imperceptible to the network node **16**. Some such procedures and functionalities may be known and practiced in the art. In certain embodiments, measurements may involve proprietary WD signaling facilitating the host computer's **24** measurements of throughput, propagation times, latency and the like. In some embodiments, the measurements may be implemented in that the software **48**, **90** causes messages to be transmitted, in particular empty or ‘dummy’ messages, using the OTT connection **52** while it monitors propagation times, errors, etc.

[0136] Thus, in some embodiments, the host computer **24** includes processing circuitry **42** configured to provide user data and a communication interface **40** that is configured to forward the user data to a cellular network for transmission to the WD **22**. In some embodiments, the cellular network also includes the network node **16** with a radio interface **62**. In some embodiments, the network node **16** is configured to, and/or the network node's **16** processing circuitry **68** is configured to perform the functions and/or methods described herein for preparing/initiating/maintaining/supporting/ending a transmission to the WD **22**, and/or preparing/terminating/maintaining/supporting/ending in receipt of a transmission from the WD **22**.

[0137] In some embodiments, the host computer **24** includes processing circuitry **42** and a communication interface **40** that is configured to a communication interface **40** configured to receive user data originating from a transmission from a WD **22** to a network node **16**. In some embodiments, the WD **22** is configured to, and/or comprises a radio interface **82** and/or processing circuitry **84** configured to perform the functions and/or methods described herein for preparing/initiating/maintaining/supporting/ending a transmission to the network node **16**, and/or preparing/terminating/maintaining/supporting/ending in receipt of a transmission from the network node **16**.

[0138] Although FIGS. **5** and **6** show various “units” such as, and scheduling unit **32** and FSR unit **34** as being within a respective processor, it is contemplated that these units may be implemented such that a portion of the unit is stored in a corresponding memory within the processing circuitry. In other words, the units may be implemented in hardware or in a combination of hardware and software within the processing circuitry.

[0139] FIG. **7** is a flowchart illustrating an example method implemented in a communication system, such as, for example, the communication system of FIGS. **5** and **6**, in accordance with one embodiment. The communication system may include a host computer **24**, a network node **16** and a WD **22**, which may be those described with reference to FIG. **6**. In a first step of the method, the host computer **24** provides user data (Block S**100**). In an optional substep of the first step, the host computer **24** provides the user data by executing a host application, such as, for example, the host application **50** (Block S**102**). In a second step, the host computer **24** initiates a transmission carrying the user data to the WD **22** (Block S**104**). In an optional third step, the network node **16** transmits to the WD **22** the user data which was carried in the transmission that the host computer **24** initiated, in accordance with the teachings of the embodiments described throughout this disclosure (Block S**106**). In an optional fourth step, the WD **22** executes a client application, such as, for example, the client application **92**, associated with the host application **50** executed by the host computer **24** (Block S**108**).

[0140] FIG. **8** is a flowchart illustrating an example method implemented in a communication system, such as, for example, the communication system of FIG. **5**, in accordance with one embodiment. The communication system may include a host computer **24**, a network node **16** and a WD **22**, which may be those described with reference to FIGS. **5** and **6**. In a first step of the method, the host computer **24** provides user data (Block S**110**). In an optional substep (not shown) the host computer **24** provides the user data by executing a host application, such as, for example, the host application **50**. In a second step, the host computer **24** initiates a transmission carrying the user data to the WD **22** (Block S**112**). The transmission may pass via the network node **16**, in accordance with the teachings of the embodiments described throughout this disclosure. In an optional third step, the WD **22** receives the user data carried in the transmission (Block S**114**).

[0141] FIG. **9** is a flowchart illustrating an example method implemented in a communication system, such as, for example, the communication system of FIG. **5**, in accordance with one embodiment. The communication system may include a host computer **24**, a network node **16** and a WD **22**, which may be those described with reference to FIGS. **5** and **6**. In an optional first step of the method, the WD **22** receives input data provided by the host computer **24** (Block S**116**). In an optional substep of the first step, the WD **22** executes the client application **92**, which provides the user data in reaction to the received input data provided by the host computer **24** (Block S**118**). Additionally or alternatively, in an optional second step, the WD **22** provides user data (Block S**120**). In an optional substep of the second step, the WD provides the user data by executing a client application, such as, for example, client application **92** (Block S**122**). In providing the user data, the executed client application **92** may further consider user input received from the user. Regardless of the specific manner in which the user data was provided, the WD **22** may initiate, in an optional third substep, transmission of the user data to the host computer **24** (Block S**124**). In a fourth step of the method, the host computer **24** receives the user data transmitted from the WD **22**, in accordance with the teachings of the embodiments described throughout this disclosure (Block S**126**).

[0142] FIG. **10** is a flowchart illustrating an example method implemented in a communication system, such as, for example, the communication system of FIG. **5**, in accordance with one embodiment. The communication system may include a host computer **24**, a network node **16** and a WD **22**, which may be those described with reference to FIGS. **5** and **6**. In an optional first step of the method, in accordance with the teachings of the embodiments described throughout this disclosure, the network node **16** receives user data from the WD **22** (Block S**128**). In an optional second step, the network node **16** initiates transmission of the received user data to the host computer **24** (Block S**130**). In a third step, the host computer **24** receives the user data carried in the transmission initiated by the network node **16** (Block S**132**).

[0143] FIG. **11** is a flowchart of an example process in a wireless device **22** according to some embodiments of the present disclosure. One or more blocks described herein may be performed by one or more elements of wireless device **22** such as by one or more of processing circuitry **84** (including the FSR unit **34**), processor **86**, radio interface **82** and/or communication interface **60**. Wireless device **22** is configured to determine whether a first signal reception, FSR, condition is met (Block S**134**). The process also includes determining whether to operate a second signal in a radio resource Rr starting at a time T**2** based at least in part on whether the FSR condition is met (Block S**136**).

[0144] FIG. **12** is a flowchart of an example process in a wireless device **22** according to some embodiments of the present disclosure. One or more blocks described herein may be performed by one or more elements of wireless device **22** such as by one or more of processing circuitry **84** (including the FSR unit **34**), processor **86**, radio interface **82** and/or communication interface **60**. Wireless device **22** is configured to determine whether a first signal reception, FSR, condition is met, the FSR condition including one of receipt and availability of at least N first signals during a time interval ΔT ending at a time T**2**, N being an integer greater than zero (Block S**138**). The process also includes, provided that the FSR condition is met, operating a second signal on a radio resource at the time T**2** (Block S**140**).

[0145] In some embodiments, the method also includes prioritizing downlink reception over uplink transmission during the time interval ΔT. In some embodiments, the method also includes prioritizing reception of a reference signal over transmission of a random access. In some embodiments, the second signal is a paging signal and the resource is a paging resource. In some embodiments, when the second signal is a downlink signal received by the WD **22**, the second signal includes at least one of a paging signal and system information. In some embodiments, when the second signal is an uplink signal transmitted by the WD **22**, the second signal includes at least one of a random access signal, a sounding reference signal, an msgA, an msg1 and an uplink transmission using configured grant-small data transmission (CG-SDT). In some embodiments, the method includes, when the second signal includes a paging signal, prioritizing downlink reception of at least N first reference signals to enable synchronization between the WD **22** and the network node prior to a paging occasion that starts at the time T**2**. In some embodiments, the FSR condition includes receiving at least N1 number of first signals during the time interval ΔT that have a bandwidth exceeding a first threshold. In some embodiments, the FSR condition includes receiving at least N2 first signals during the time interval ΔT that have a bandwidth that falls below a second threshold, N2 being an integer greater than 1. In some embodiments, the method also includes selecting between two step random access and four-step random access when the FSR condition is met and the second signal is a random access signal. In some embodiments, the method includes refraining from selecting between two step random access and four-step random access when the FSR condition is not met. In some embodiments, the method includes performing a random access transmission in a physical random access channel, PRACH, occasion when the FSR condition is met. In some embodiments, the method includes, when the FSR condition is not met, one of postponing, deferring and delaying operating the second signal. In some embodiments, the method includes, when the FSR condition is not met, one of postponing, deferring and delaying operating the second signal until the FSR condition is met. In some embodiments, the method includes, when the FSR condition is not met, one of discarding and canceling operating the second signal. In some embodiments, the method includes, when the FSR condition is not met, one of discarding and canceling operating the second signal after M failed attempts to operate the second signal, M being an integer greater than zero. In some embodiments, when the WD **22** is in a low-activity radio resource control, RRC state, configuring the WD **22** to re-synchronize with the network node and to perform automatic gain control during the time interval ΔT. In some embodiments, ΔT is determined based at least in part on one of a synchronization status of the WD **22**, a discontinuous reception time, and a reference signal transmission periodicity. In some embodiments, operating the second signal includes receiving one of a paging signal, performing a random access procedure, and transmitting a small data transmission, SDT.

[0146] FIG. **13** is a flowchart of an example process in a network node **16** for rank restriction for multi-panel uplink (UL) transmission. One or more blocks described herein may be performed by one or more elements of network node **16** such as by one or more of processing circuitry **68** (including the scheduling unit **32**), processor **70**, radio interface **62** and/or communication interface **60**. Network node **16** may be configured to transmit to the WD **22** at least N first signals during the time interval ΔT ending at a time T**2**, N being an integer greater than zero (Block S**142**). The process also includes scheduling uplink resources for uplink transmissions by the WD **22** after the time T**2**, the uplink transmissions being responsive to one of receipt and availability of the at least N first signals during the time interval ΔT (Block S**144**). In some embodiments, the method includes scheduling at least one of a two-step random access and a four-step random access while avoiding overlapping synchronization signal resources and uplink resources in the time domain. In some embodiments, the time interval ΔT is greater than a synchronization signal periodicity plus a first switching time from uplink receipt to downlink transmission. In some embodiments, the method includes scheduling the uplink resources during a time period between: a start of a synchronization signal minus the first switching time; and an end of the synchronization signal plus a second switching time from downlink transmission to uplink receipt. In some embodiments, the at least N first signals are synchronization signal and physical broadcast channel signal blocks, SSBs.

[0147] Having described the general process flow of arrangements of the disclosure and having provided examples of hardware and software arrangements for implementing the processes and functions of the disclosure, the sections below provide details and examples of arrangements for proactive (SSB)/(TRS) reception procedures for half-duplex operation.

[0148] In the following embodiments, solutions are described using generic terms for DL reception or DL signal reception and UL transmission or UL signal transmission. DL reception can include reception of one or more DL signals. Examples of DL signals are physical DL channels and DL physical signals. The physical channel (DL or UL) may carry higher layer information e.g., control, data, etc. Examples of DL physical channels are PDSCH, PDCCH, PBCH, CORSET, etc.

Examples of physical signals (DL or UL) are reference signals (may also be called as pilot signals, training sequence, etc.). Examples of DL RS are PSS, SSS, SSB, CSI-RS, PRS, TRS, DMRS, reference signals (e.g., PSS, SSS, DMRS) within SSB, etc. Similarly, UL transmission can include physical UL channels or signals. Examples of UL physical channels are PUSCH, PUCCH, SR etc. Examples of UL RSs are DMRS, SRS, etc. When DL reception or UL transmission is described as being dynamically scheduled or semi-statically configured, all the mentioned physical channels and signals may be covered.

[0149] The term time resource used herein may correspond to any type of physical resource or radio resource expressed in terms of length of time. Examples of time resources are: symbol, sub-slot, mini-slot, time slot, subframe, radio frame, transmission time interval (TTI), interleaving time, frame, system frame number (SFN) cycle, hyper-SFN (H-SFN) cycle, etc.

[0150] Some embodiments are intended for NR HD-FDD capable WDs. An example of a NR HD-FDD capable WD **22** is a NR HD-FDD Type-A WD. They provide WD behavior in handling DL/UL collision for HD-FDD WDs. However, the solutions are not necessarily restricted to HD-FDD WDs.

[0151] In the following sections the term dropping reception of a signal may imply that the WD **22** does not receive the signal. The term dropping transmission of a signal may imply that the WD **22** does not transmit the signal. The term dropping signal reception may also interchangeably be called cancelling, discarding, abandoning, stopping reception of the signal, not receiving the signal, etc. Similarly, the term dropping signal transmission may also interchangeably be called cancelling, discarding, abandoning, stopping transmission of the signal, not transmitting the signal, etc.

[0152] Some embodiments are applicable to a WD **22** configured in HD-FDD mode and served by at least one cell, a first cell (cell1). The WD **22** may be configured to operate at least one second signal (S**2**) in a radio resource (Rr) starting at a time instance, T**2**, in a cell. The cell may be cell1 or another cell, e.g., a second cell (cell2). The operation of S**2** may include the WD **22** performing one or more of: receiving S**2** and transmitting S**2**. In order to operate S**2**, or prior to operating S**2**, the WD **22** may receive a first signal (S**1**) in a cell (e.g., cell1 or cell2).

[0153] In some embodiments, the WD **22** is configured to operate the signal, S**2**, in the resource, Rr, and may perform the following steps: [0154] Determine whether a first signal reception (FSR) condition is met by the WD **22**; [0155] Operate S**2** in Rr based on whether the FSR is met by the WD **22**; [0156] If the WD **22** fulfils at least one FSR condition, then the WD **22** is expected to operate or it can operate or is required to operate S**2** in the resource Rr starting at T**2**. Otherwise, the WD **22** is not expected to operate or is not required to operate or may not operate S**2** in the resource Rr.

[0157] First Signal Reception (FSR) is determined by the WD **22** based on one or more rules, which may be pre-defined or configured by the network node **16**.

[0158] Examples of rules may include the following: [0159] In one example of the rule, the WD **22** meets FSR provided that the WD **22** can receive or has received at least N number of a first signal (S**1**) during a time period (ΔT) before T**2** or between time instances T**1** and T**2**; where ΔT=(T**2**−T**1**) and T**1**<T**2** e.g., T**1** is the time instance occurring before T**2**. The time period ΔT may be pre-defined, configured by the network node **16** or determined by the WD **22** autonomously. The time period ΔT may depend on S**1** and/or S**2** configuration parameters e.g., their periodicities etc. In one example, N=1. In another example, N>1 e.g., N=4; [0160] In another example of the rule, the WD **22** meets FSR provided that the WD **22** can receive or has received at least N number of S**1** each with bandwidth (BW) that is larger than or equal to a threshold (Hb) during a ΔT before T**2** or between time instances T**1** and T**2**. N may further depend on the BW. Example of Hb is 48× subcarrier spacing (SCS), where SCS is the subcarrier scaping, e.g., 15 kHz, 30 kHz;

[0161] In another example of the rule, the WD **22** meets FSR provided that the WD **22** can receive or has received at least N1 number of S**1** each with BW≥Hb or can receive at least N2 number of S**1** if BW of at least one S**1** is less than Hb during a time period (ΔT) before T**2** or between time instances T**1** and T**2**. N1 and N2 are different. In one example, N1<N2. N1 and N2 may further depends on the BW. Example of Hb is 48×SCS, where SCS is the subcarrier scaping, e.g., 15 kHz, 30 KHz.

[0162] The parameters T**1**, T**2** and ΔT may be pre-defined, configured by the network node **16** or autonomously determined by the WD **22**. In one example, the WD **22** may receive S**1** in the same cell in which it operates S**2** e.g., both signals in cell1, or both signals in cell2. In another example, the WD **22** may receive S**1** in one cell while it may operate S**2** in another cell e.g., signals S**1** and S**2** in cell1 and cell2 respectively, or signals S**1** and S**2** in cell2 and cell1 respectively.

[0163] In the above examples the rules may be phrased as follows: [0164] " . . . UE can receive or has received at least N number of S**1** . . . ", may also be referred to as, " . . . at least N number of S**1** is available or was available at the UE . . . ". [0165] " . . . UE can receive or has received at least N number of S**1** each of BW≥Hb . . . ", may also be referred to as, " . . . at least N number of S**1** each with BW≥Hb is available or was available at the UE . . . ". [0166] " . . . UE can receive or has received at least N1 number of S**1** each with BW≥Hb or can receive at least N2 number if BW of at least one S**1**<Hb . . . ", may also be referred to as, " . . . at least N1 number of S**1** each with BW≥Hb is available or was available at the UE . . . ".

[0167] The N or N1 or N2 number of S**1** may refer to instances of signal S**1**. Each instance may correspond to a time and/or frequency resource e.g., one or more time resources, resource blocks etc. In order to be able to receive the signal, S**1**, the WD **22** needs to turn on its receiver i.e., operate in DL reception mode. For example, if the WD **22** is configured in UL transmission (or configured UL resources) in T**2**, then the WD **22** may change or switch its transceiver to the DL reception mode at least during the N instances (e.g., time and/or frequency resources) to be able to receive at least N number of S**1** between T**2** and T**1**. However, in between the radio resources containing S**1**, the WD **22** may be in either operating mode (DL or UL). The WD **22** may switch to DL reception mode autonomously, based on a pre-defined rule or based on a message received from the network node **16**.

[0168] The WD **22** may be required to meet FSR conditions to operate S**2**, so that the WD **22** transceiver is ready or tuned for operating S**2**. Therefore, the WD **22** may use at least N number of S**1** to perform one or more radio preparatory operations or procedures. Examples of radio preparatory procedures are automatic gain control (AGC) setting or AGC settling, time tracking or synchronization, frequency tracking or synchronization, automatic frequency correction (AFC) etc.

[0169] In one example, the WD **22** may be configured such that the WD **22** may have to operate S**2** in Rr starting from T**2**. In this case, the WD **22** may receive at least N1 number of S**1** between T**2** and T**1**. In another example, the WD **22** may be configured with the resources to operate S**2** in Rr starting from T**2**. But whether the WD **22** may operate S**2** in Rr may depend on one or more triggering conditions even if the WD **22** meets at least one FSR condition. Examples of triggering conditions are WD **22** losing synchronization with the cell e.g., cell1, the WD **22** needs to acquire grant or resources, etc.

[0170] If the WD **22** does not operate S**2** due to not meeting the at least one FSR condition, then the WD **22** may further perform one or more tasks or procedures or actions. Examples of such tasks are: [0171] Postponing, deferring or delaying the operation of S**2** at a later time e.g., checking again the FRS condition later and transmitting S**2** after T**2** in another radio resource if the FSR condition is met; [0172] Discarding or canceling the operation of S**2** after M number of fail attempts to operate S**2**. In one example M=1 and in another example M>1. M may be pre-defined or configured by the network node **16**.

[0173] Examples of S**1** include reference signals (RS) e.g., PSS, SSS, SSB, CSI-RS, DMRS, PRS, etc.

[0174] Examples of S**2** signals in DL operation includes paging, system information (SI) (e.g., SIB1, SIB2, etc.).

[0175] Examples of S**2** signals in UL operation include random access (RA), PUSCH, PUCCH,

CG-SΔT transmission resource, SRS, msgA, msg1, etc.
[0176] The above general concept is now described with several specific examples of different specific combinations of S**1** and S**2**.
[0177] FIG. **12** is an example of the WD **22** operating N number of signals, S**1** (e.g., N number of SSBs), within ΔT (ΔT=T.sub.2−T.sub.1) before the start (T.sub.2) of the radio resource containing the signal, S**2** (e.g., paging, RA).
[0178] In one example scenario, a WD **22** is capable of, or configured to, operate in HD-FDD mode served by a first cell (cell1) which is managed or served by a first network node **16** (NN1), e.g., gNB. The WD **22** may further operate in, or be configured in, a low activity RRC state (e.g., such as RRC IDLE state, RRC INACTIVE state etc.). During the time period ΔT**1** before a time resource containing a paging occasion (PO, e.g., for the paging reception), the HD-FDD WD **22** prioritizes the DL reception (e.g., SSB reception) over the UL transmission (e.g., random access or any other UL transmission). For example, during time period ΔT**1**, the WD **22** switches to DL during the resources where one or more DL RSs (e.g., the SSBs) are available at the WD **22**. In other resources during time period ΔT**1** which do not contain the DL RSs, the WD **22** may be in DL or UL. The time resource (Rp) containing at least one PO may occur at or start at certain time instance, T**2**. The WD **22** may further prioritize certain types of DL reception over any UL transmission during ΔT**1** before T**2**. In one example, the WD **22** prioritizes the TRS reception over random access or any other UL transmission during ΔT**1** before T**2**.
[0179] Therefore, in this example, SSB and/or TRS correspond to signal S**1** and paging signal in a paging resource (e.g., in PO) correspond to signal S**2**.
[0180] In this scenario, the NW1 may configure the following types of periodic DL signals: [0181] SS/PBCH block (SSB) with the periodicity T.sub.SSB. An example of T.sub.SSB is 20 ms; [0182] CSI-RS for tracking (TRS) with the periodicity T.sub.TRS. An example of T.sub.TRS is 20 ms; and/or [0183] Paging occasions with the periodicity T.sub.PO. An example of T.sub.PO is 2560 ms.
[0184] In addition, the NW1 (e.g., gNB) may configure any other DL scheduling for WD **22** to receive when it is in IDLE or INACTIVE states.
[0185] The NW1 (e.g., gNB) also configures the RACH resources with the periodicity T.sub.RACH. An example of T.sub.RACH is 40 ms. The network node may configure any other UL transmission resources for the WD **22** to use to transmit when it is in low activity RRC state (e.g., RRC IDLE state or INACTIVE state).
[0186] When the HD-FDD WD **22** is in low activity RRC state (e.g., RRC IDLE state or INACTIVE state), the WD **22** is scheduled, required or expected to wake up (e.g., from DRX OFF duration) and become active mode (e.g., into DRX ON duration) every T.sub.PO. When the WD **22** is not in active mode, the WD **22** is in the sleep mode and stops almost all the RF and Baseband processors. During the period ΔT**1** (SSB/TRS measurement window) before the paging occasion in T**2**, the WD **22** receives SSB and/or TRS to re-synchronize with the network node and to perform AGC. This operation is also interchangeably referred to as time and/or frequency tracking and/or AGC setting. If the HD-FDD WD **22** is configured with UL resources which are fully or partially overlapped with SSB/TRS, then the WD **22** prioritizes to receive SSB/TRS and skip UL transmission. Example of an UL transmission is random access.
[0187] The period ΔT**1** (SSB/TRS measurement window) may be configured by the network node **16**, pre-defined, or function of paging occasion period, e.g., f(T.sub.PO)=min (160 ms, T.sub.DRX/10). In one example, the WD **22** may determine the length of ΔT**1** autonomously based on its receiver synchronization status, e.g., based on a time since a last reception, transmission, a time since last time WD **22** has been in active mode, a time since last paging, etc. In another example, the length of ΔT**1** may depend on T.sub.DRX and T.sub.RS (reference signal transmission periodicity, also referred to as T.sub.SSB). In yet another example, length of ΔT**1** may depend on receiver type, e.g., whether it is a WD **22** of reduced complexity (e.g., 1 receive antenna).
[0188] FIG. **14** illustrates an example embodiment where an SSB is scheduled with the periodicity

T.sub.SSB. A Paging Occasion is scheduled in t**5**, and UL resources are scheduled in t**7** and t**8**. In this example, it is assumed that the WD **22** is to receive SSBs for the duration ΔT**1** before the start of paging occasion, T**2**. In this example, 4 SSBs are transmitted during ΔT**1**. During this duration, the WD **22** is also configured and/or scheduled with UL transmissions in t**7** and t**8**. Since no SSB is transmitted during the UL resource in t**7**, the WD **22** switches to UL and can perform UL transmission. On the other hand, SSB is transmitted during the UL resource in t**8**. Thus, the WD **22** does not switch to UL, but instead, the WD **22** receives the SSB at t**3**. In this case, the UL transmission at t**8** might be dropped or postponed. In this example, it is assumed that the resynchronization (AGC or time/frequency tracking) is based on SSB. In another example, the WD **22** may use CSI-RS/TRS to perform the same operation. The length of ΔT**1** may also depend on the type of RS used for performing the resynchronization. In another example, the length of ΔT**1** may also depend on whether the time resources are fully or partially overlapping. The time period ΔT**1** may be shorter if the DL and UL resources are partially overlapping compared to if they are fully overlapping.

[0189] In one specific example based on FIG. **15**, assuming that the DL measurement occasions during the time period ΔT**1** are guaranteed in the WD **22**, then the WD **22** may be required to meet the paging requirements, i.e., to correctly receive or to not miss the paging message at time t**5**. This implies that the WD **22** measures on the DL signals and performs the resynchronization towards the serving cell during time period t**5**.

[0190] In another specific example based on FIG. **16**, if WD **22** will use SSB in t**3** for cell reselection measurements and SSB in t**4** for paging AGC retuning, then the UL transmission at t**8** might also be dropped or postponed.

[0191] In another specific example based on FIG. **16**, where it is assumed that the DL measurement occasions during time period ΔT**1** cannot be guaranteed in the WD **22** due to more critical UL transmission (e.g., public safety messages, positioning message) taking place in t**8**, then the WD **22** may be unable (drops) to receive the SSB in t**3**, in this case the WD **22** may not be required to fulfill the paging reception requirements, i.e., the WD **22** may be allowed to miss the paging message at time t**5**.

[0192] In another specific example based on FIG. **17**, the WD **22** will use an SSB in t**3** for cell reselection measurements but use SSB in t**4** for paging AGC retuning. In this case, the WD **22** may still be required to fulfill the paging reception requirements. In another embodiment, when the WD **22** is in CONNECTED mode, during the period ΔT**1** before the DL signal reception for the WD **22** configured with C-DRX, the HD-FDD WD **22** prioritizes SSB reception over random access or any other UL transmission. Optionally, the WD **22** prioritizes TRS reception over random access or any other UL transmission.

[0193] In this scenario, the network node **16** may configure the following periodic DL signals:

[0194] SS/PBCH block (SSB) with the periodicity T.sub.SSB. Example of T.sub.SSB is 20 ms;

[0195] CSI-RS for tracking (TRS) with the periodicity T.sub.TRS. Example of T.sub.TRS is 20 ms; and [0196] Connected mode DRX (C-DRX) with the periodicity T.sub.DRX. Example of T.sub.PO is 320 ms.

[0197] The network node **16** also configures the UL resources in CONNECTED mode. The example of UL resources is PUCCH, CG-PUSCH, SRS.

[0198] When the HD-FDD WD **22** is in CONNECTED mode, WD **22** is scheduled to wake and become active mode during the on-duration every T.sub.DRX. When WD **22** is not in active mode, the WD **22** is in the sleep mode. During the period ΔT**1** (SSB/TRS measurement window) before the on-duration, the WD **22** may receive SSB and/or TRS to re-synchronize with the network node and to perform AGC. If the HD-FDD WD **22** is configured with UL resources fully or partially overlapped with SSB/TRS, the WD **22** prioritize reception of SSB/TRS and may skip UL transmission.

[0199] The SSB/TRS measurement window may be configured by the network, pre-defined, or function of DRX period, e.g., f(T.sub.DRX)=min (80 ms, T.sub.DRX/10). In one example, the WD **22** may determine the length of ΔT**1** autonomously based on its receiver synchronization status, e.g., based on time since last reception, transmission, time since last time WD **22** has been in active mode, time since last paging, etc. In another example, the length of ΔT**1** may depend on T.sub.DRX and T.sub.RS (reference signal transmission periodicity, also referred to as T.sub.SSB). In yet another example, the duration of ΔT**1** may depend on receiver type, e.g., whether it is a WD **22** of reduced complexity (e.g., 1 Rx).

[0200] FIG. **16** illustrates an example embodiment where SSB are scheduled with the periodicity T.sub.SSB. The On-duration is scheduled in t**5**, and UL resources are scheduled in t**7**, t**8**, and t**9**. In this example, it is assumed that the WD **22** will receive SSBs for the duration ΔT**1** before the On-duration. In this example, 3 SSBs are transmitted during ΔT**1**. In the duration, the WD **22** needs three UL transmissions in t**7**, **18**, and t**9**. Since no SSB is transmitted during the UL resource in t**7**, the WD **22** switches to UL and can perform UL transmission. The WD **22** can also perform UL transmission at t**9**. On the other hand, SSB are transmitted during the UL resource in t**8**, and the WD **22** does not switch to UL, and will not receive the SSB at t**3**.

[0201] In another specific example based on FIG. **18**, where an SSB is scheduled with the periodicity T.sub.SSB. In the duration, the WD **22** needs three UL transmissions in t**7**, t**8**. An SSB is transmitted during the UL resource in t**8**, but the WD **22** is unable (drops) to receive the SSB in t**3** due to more critical UL transmissions (e.g., RACH for Handover, or Link recovery etc.) taking place in t**8**.

[0202] Examples of one or more rules, which may be specified or configured to define the WD behavior may include one or more of the following [0203] The HD-FDD capable WD **22** is expected to receive or shall receive a paging in a paging resource (Rp) (e.g., paging occasion) in a cell provided that at least N number of RSs (e.g., SSB, TRS, etc.) are available at the WD **22** during the last Tp period before the paging resource, Rp. It may also be specified that the WD **22** is expected to meet or shall meet one or more requirements associated with a paging reception if the above condition on N number of RSs is met; [0204] The HD-FDD capable WD **22** is expected to receive or shall receive a paging in a paging resource (Rp) (e.g., paging occasion) in a cell provided that the WD **22** can receive or is able to receive at least N number of RSs (e.g., SSB, TRS, etc.) during the last Tp period before the paging resource, Rp. It may also be specified that the WD **22** is expected to meet or shall meet one or more requirements associated with a paging reception if the above condition on N number of RSs is met; [0205] The HD-FDD capable WD **22** is not expected to receive or may not receive or is not required to receive or is allowed to miss a paging in a paging resource (Rp) (e.g., paging occasion) in a cell less than N number of RSs (e.g., SSB, TRS, etc.) is available at the WD **22** during the last Tp period before the paging resource, Rp. It may also be specified that the WD **22** is not expected to meet or may not meet or is not required to meet one or more requirements associated with a paging reception if the above condition on N number of RSs is not met; [0206] The HD-FDD capable WD **22** is not expected to receive or may not receive or is allowed to miss a paging in a paging resource (Rp) (e.g., paging occasion) in a cell provided that the WD **22** cannot receive or is unable to receive at least N number of RSs (e.g., SSB, TRS, etc.) during the last Tp period before the paging resource, Rp. It may also be specified that the WD **22** is not expected to meet or may not meet or is not required to meet one or more requirements associated with a paging reception if the above condition on N number of RSs is not met; [0207] The HD-FDD capable WD **22** drops or discards or shall drop or discard or is allowed to miss a paging in a paging resource (Rp) (e.g., paging occasion) in a cell if less than N number of RSs (e.g., SSB, TRS, etc.) is available at the WD **22** during the last Tp period before the paging resource, Rp. It may also be specified that the WD **22** is not expected to meet or may not meet or is not required to meet one or more requirements associated with a paging reception if the above condition on N number of RSs is not met; and/or [0208] The HD-FDD capable WD **22** drops or discards or shall drop or discard or is allowed to miss a paging in a paging resource (Rp) (e.g., paging occasion) in a cell if the WD **22** cannot receive at least N number of RSs (e.g., SSB, TRS, etc.) during the last Tp period before the paging resource, Rp. It may also be specified that the WD **22** is not expected to meet or may not meet or is not required to meet one or more requirements associated with a paging reception if the above condition on N number of RSs is not met.

[0209] In another example embodiment, an HD-FDD WD **22** receives several SSBs before the random access attempts if both 4-step RA type and 2-step RA type are configured. If the SSBs are fully or partially overlapped with the scheduled UL resources, the WD **22** prioritizes to receive the SSB and skip the scheduled UL transmission.

[0210] Therefore, in this example, the SSB corresponds to signal, S**1** and random access transmission/signal in a RACH resource (e.g., in RACH occasion) corresponds to signal, S**2**:

[0211] Step 1: When the HD-FDD WD **22** needs random access attempts, WD **22** start to schedule to receive several SSBs before attempting random access on the scheduled random access occasion.

[0212] For example, the WD **22** may schedule to receive N SSBs for ΔT**1** period before the random access attempt, e.g., N=4 and ΔT**1**=320 ms. If the scheduled SSBs are less than N during ΔT**1**, the WD **22** will schedule receive all the SSBs for ΔT**1** period.

[0213] As another example, the WD **22** may schedule to receive N consecutive SSBs just before the random access, e.g., N=4.

[0214] As another example, the WD **22** may schedule to receive all the SSBs for T**1** period before the random access, e.g., T**1**=160 ms. [0215] Step 2: When the WD **22** is configured with UL resources and they are fully or partially overlapped with the SSBs in the time domain which are scheduled to be measured in Step 1, the WD **22** prioritizes to measure SSB and WD **22** skips to UL transmission on the scheduled UL resources. Examples of UL resources are PUCCH and SRS.

[0216] If the WD **22** is configured with UL resources and they are not overlapped with the SSBs in the time domain, the WD **22** may switch to UL carrier and attempt UL transmission if necessary.

[0217] FIG. **19** is an example of the SSB measurement prioritization before random access. In this example, a RACH occasion is scheduled in t**4** and **3** UL resources are scheduled in t**1**, t**2**, and t**3**. In the DL carrier, the SSB is transmitted with the periodicity T.sub.SSB. The WD **22** needs to measure SSB samples over ΔT**1** for RSRP measurements and the WD **22** is going to attempt a random access in t**4**. In this example, the WD **22** schedules to measure 4 SSBs from t**5**. During ΔT**1**, there are three configured UL resources. The WD **22** switches to UL and transmits signals in t**1** and t**2**. However, in this example, the WD **22** does not transmit signal in t**3** because it overlaps with SSB transmission in DL. After the WD **22** measures 4 SSBs during T**1**, the WD **22** estimates RSRP and select 4-step RA or 2-step RA according to the measurement results.

[0218] If the WD **22** is configured with UL resources and they are not overlapped with the SSBs in the time domain, but the time between SSB and UL resources are within the switching period between UL and DL in half-duplex operation, the WD **22** may receive SSB and the WD **22** skips to UL transmission on the scheduled UL resources. For example, it is assumed that SSB transmission ends at ta and the network node schedule to start UL transmission at TB. If the time difference TB-TA exceeds the DL-to-UL switching timing difference for the WD **22** half-duplex operation, the WD **22** may receive SSB and skip the UL transmission at TB.

[0219] FIG. **20** is an example of UL transmission after SSB measurements. In this example, an SSB transmission starts between t.sub.1 and t.sub.2, and the HD-FDD DL-to-UL switching period is given by T.sub.DL-to-UL. In Example (a), the UL resource is configured from t.sub.3 and (t.sub.3−t.sub.2)>T.sub.DL-to-UL. In this case, the WD **22** will switch to UL before t.sub.3 and transmit UL signals. On the other hand, Example (b) the UL resource is configured from t.sub.3′ and (t.sub.3′−t.sub.2)<T.sub.DL-to-UL. In this case, the WD **22** skips the transmission of UL signals. [0220] Step 3: Before the random access attempt, the WD **22** decides the RA-type based on the measured SSBs. The WD **22** starts to transmit the random access preamble on the scheduled random access occasion based on the selected RA-type.

[0221] In another embodiment, when the network node **16** schedules both 4-step RA type and 2-

step RA type to the HD-FDD WDs, the network node **16** may avoid the overlapping between SSB and UL resources in the time domain.

[0222] In this embodiment, the WD **22** informs the network node whether it operates with HD-FDD. When the network node **16** is indicated the HD-FDD operation by the WD **22**, it also knows the switching time from DL-to-UL (T.sub.DL-to_UL) and time from UL-to-DL (T.sub.UL-to_DL). The switching time DL-to-UL and UL-to-DL may be the same or different. The switching time may be informed by the WD **22** or pre-defined.

[0223] The network node **16** schedules an SSB with the period T.sub.SSB. An example of T.sub.SSB is 20 ms. When the network node configures 4-step RA type and 2-step RA type for random access procedure, the network node schedules UL resources for the HD-FDD WDs so that they are outside SSB transmission plus DL-to-UL/UL-to-DL switching time in the time domain. Examples of UL resources are PUCCH, SRS, and PRACH.

[0224] For example, if SSB transmission starts at T.sub.SSB_start and ends at T.sub.SSB_end, the network node does not schedule UL resource at least in the time window between (T.sub.SSB_start−T.sub.UL-to-DL) and (T.sub.SSB_end+T.sub.DL-to-UL).

[0225] If the network node **16** needs to schedule the UL resources during the time window between (T.sub.SSB_start−T.sub.UL-to-DL) and (T.sub.SSB_end+T.sub.DL-to-UL), the network node **16** may expect that the HD-FDD WD **22** won't transmit UL signal.

[0226] Examples of one or more rules, which may be specified or configured to define the WD **22** behavior may include one or more of the following: [0227] The HD-FDD capable WD **22** is expected to perform or shall perform selection between 2-step RA and 4-step RA for RA transmission in a cell provided that at least N number of RSs (e.g., SSB, etc.) are available at the WD **22** during the last Tp period before the RA selection or RA transmission resource (e.g., RA transmission occasion). It may also be specified that the WD **22** is expected to meet or is required to meet one or more requirements associated with a RA selection between 2-step RA and 4-step RA, for RA transmission if the above condition on N number of RSs is met; [0228] The HD-FDD capable WD **22** is expected to perform selection between 2-step RA and 4-step RA for RA transmission in a cell provided that the WD **22** can receive at least N number of RSs (e.g., SSB etc.) is available at the WD **22** during the last Tp period before the RA selection or RA transmission resource (e.g., RA transmission occasion). It may also be specified that the WD **22** is expected to meet or is required to meet one or more requirements associated with a RA selection between 2-step RA and 4-step RA, for RA transmission if the above condition on N number of RSs is not met; [0229] The HD-FDD capable WD **22** is not expected to perform or is not required to perform or may not perform selection between 2-step RA and 4-step RA for RA transmission in a cell if less than N number of RSs (e.g., SSB etc.) is available at the WD **22** during the last Tp period before the RA selection or RA transmission resource (e.g., RA transmission occasion). It may also be specified that the WD **22** is not expected to meet or is not required to meet one or more requirements associated with a RA selection between 2-step RA and 4-step RA, for RA transmission if the above condition on N number of RSs is not met; [0230] The HD-FDD capable WD **22** is not expected to perform or is not required to perform or may not perform selection between 2-step RA and 4-step RA for RA transmission in a cell if the WD **22** cannot receive at least N number of RSs (e.g., SSB etc.) during the last Tp period before the RA selection or RA transmission resource (e.g., RA transmission occasion). It may also be specified that the WD **22** is not expected to meet or is not required to meet one or more requirements associated with a RA selection between 2-step RA and 4-step RA, for RA transmission if the above condition on N number of RSs is not met; [0231] The HD-FDD capable WD **22** is expected to perform or is required to perform or shall perform RA transmission in a PRACH occasion in a cell if the WD **22** can receive at least N number of RSs (e.g., SSB etc.) associated with the PRACH occasion during the last Tp period before the PRACH transmission resource (e.g., PRACH occasion). It may also be specified that the WD **22** is expected to meet or is required to meet one or more requirements associated with a RA transmission if the above condition on N number of RSs is met; [0232] The HD-FDD capable WD **22** is expected to perform or is required to perform or shall perform RA transmission in a PRACH occasion in a cell if at least N number of RSs (e.g., SSB etc.) associated with the PRACH occasion is available at the WD **22** during the last Tp period before the PRACH transmission resource (e.g., PRACH occasion). It may also be specified that the WD **22** is expected to meet or is required to meet one or more requirements associated with a RA transmission if the above condition on N number of RSs is met; [0233] The HD-FDD capable WD **22** is not expected to perform or is not required to perform or may not perform RA transmission in a PRACH occasion in a cell if the WD **22** cannot receive at least N number of RSs (e.g., SSB etc.) associated with the PRACH occasion during the last Tp period before the PRACH transmission resource (e.g., PRACH occasion). It may also be specified that the WD **22** is not expected to meet or may not meet or is not required to meet one or more requirements associated with a RA transmission if the above condition on N number of RSs is not met; and/or [0234] The HD-FDD capable WD **22** is not expected to perform or is not required to perform or may not perform RA transmission in a PRACH occasion in a cell if less than N number of RSs (e.g., SSB etc.) associated with the PRACH occasion is available at the WD **22** during the last Tp period before the PRACH transmission resource (e.g., PRACH occasion). It may also be specified that the WD **22** is not expected to meet or may not meet or is not required to meet one or more requirements associated with a RA transmission if the above condition on N number of RSs is me

[0235] In another example embodiment, the HD-FDD WD **22** receives at least N number of SSBs between T**2** and T**1**, before transmitting small data in the SΔT resources in the UL.

[0236] Therefore, in this example, the SSB corresponds to signal, S**1** and SΔT transmission/signal in a RACH-SΔT resource or CG-SΔT resource corresponds to signal, S**2**.

[0237] The WD **22** may transmit small data on a RA-SΔT resource or in a CG-SΔT resource. The SΔT resource may start at time instance T**2**. If the WD **22** cannot receive at least N number of SSBs between T**2** and T**1**, then the WD **22** does not transmit the SΔT resources in the UL starting from T**2**. The WD **22** may further postpone the SΔT transmission at a later time.

[0238] In one example, the WD **22** may need to acquire different numbers of SSBs for transmitting small data using RA-SΔT resource or CG-SΔT resource, e.g., N3 number of SSBs and N4 number of SSBs for transmitting using RA-SΔT resource or CG-SΔT resource respectively. In this case the WD **22** may select SΔT resource (RA-SΔT resource or CG-SΔT resource) which meets the FSR condition. For example, if the WD **22** has acquired N3 number of SSBs then the WD **22** uses RA-SΔT resource for SΔT. If the WD **22** has acquired N4 number of SSBs, then the WD **22** uses CG-SΔT resource for SΔT. Otherwise, if the WD **22** has acquired a number of SSBs below N3 and also below N4 then the WD **22** does not transmit SΔT data.

[0239] Examples of one or more rules, which may be specified or configured to define the WD **22** behavior may include one or more of the following: [0240] The HD-FDD capable WD **22** is expected to transmit or shall transmit or is required to transmit SΔT in a SΔT resource (e.g., CG-SΔT or RA-SΔT resources) in a cell provided that at least N number of RSs (e.g., SSB, TRS, etc.) are available at the WD **22** during the last Tp period before the STD transmission resource; [0241] The HD-FDD capable WD **22** is expected to transmit or shall transmit or is required to transmit SΔT in a SΔT resource (e.g., CG-SΔT or RA-SΔT resources) in a cell provided that the WD **22** can receive at least N number of RSs (e.g., SSB, TRS, etc.) during the last Tp period before the STD transmission resource; [0242] The HD-FDD capable WD **22** is not expected to transmit or shall not transmit or is not required to transmit SΔT in a SΔT resource (e.g., CG-SΔT or RA-SΔT resources) in a cell if less than N number of RSs (e.g., SSB, TRS, etc.) is available at the WD **22** during the last Tp period before the STD transmission resource; [0243] The HD-FDD capable WD **22** is not expected to transmit or shall not transmit or is not required to transmit SΔT in a SΔT resource (e.g., CG-SΔT or RA-SΔT resources) in a cell if the WD **22** cannot receive at least N number of RSs (e.g., SSB, TRS, etc.) during the last Tp period before the STD transmission resource; [0244] The

HD-FDD capable WD **22** is expected to perform or shall perform or is required to perform selection between CG-SΔT and CG-RA based transmission schemes for SΔT transmission in a SΔT resource (e.g., CG-SΔT or RA-SΔT resources) in a cell provided that at least N number of RSs (e.g., SSB, TRS, etc.) are available at the WD **22** during the last Tp period before the STD transmission resource. [0245] The HD-FDD capable WD **22** is expected to perform or shall perform or is required to perform selection between CG-SΔT and CG-RA based transmission schemes for SΔT transmission in a cell provided that the WD **22** can receive at least N number of RSs (e.g., SSB, TRS, etc.) during the last Tp period before the STD transmission resource; [0246] The HD-FDD capable WD **22** is not expected to perform or shall not perform or is not required to perform selection between CG-SΔT and CG-RA based transmission schemes for SΔT transmission in a SΔT resource (e.g., CG-SΔT or RA-SΔT resources) in a cell if less than N number of RSs (e.g., SSB, TRS, etc.) are available at the WD **22** during the last Tp period before the STD transmission resource; and [0247] The HD-FDD capable WD **22** is not expected to perform or shall not perform or is not required to perform selection between CG-SΔT and CG-RA based transmission schemes for SΔT transmission in a cell provided that the WD **22** cannot receive at least N number of RSs (e.g., SSB, TRS, etc.) during the last Tp period before the STD transmission resource.

[0248] According to one aspect, a WD **22** is configured to communicate with a network node **16**. The WD **22** includes processing circuitry **84** configured to: determine whether a first signal reception, FSR, condition is met, determine whether to operate a second signal in a radio resource Rr starting at a time T**2** based at least in part on whether the FSR condition is met.

[0249] According to this aspect, in some embodiments, the FSR condition includes one of reception of at least N number of a first signal (S**1**) and at least N number of S**1** is available at the WD **22** during a time period (ΔT) before T**2** or between time instances T**1** and T**2**; where ΔT=T**2**−T**1** and T**1**<T**2**. In some embodiments, the FSR condition is fulfilled, then the processing circuitry **84** is further configured to postpone operation of the second signal.

[0250] According to another aspect, a method implemented in a wireless device (WD) **22** is provided. The method include determining whether a first signal reception, FSR, condition is met, and determining whether to operate a second signal in a radio resource Rr starting at a time T**2** based at least in part on whether the FSR condition is met.

[0251] According to this aspect, in some embodiments, the FSR condition includes one of reception of at least N number of a first signal (S**1**) and at least N number of S**1** is available at the WD **22** during a time period (ΔT) before T**2** or between time instances T**1** and T**2**; where ΔT=T**2**−T**1** and T**1**<T**2**. In some embodiments, the FSR condition is fulfilled, the method also includes postponing operation of the second signal.

[0252] Other example embodiments may include one or more of the following: [0253] Example 1. A wireless device (WD) configured to communicate with a network node, the WD comprising processing circuitry configured to; [0254] determine whether a first signal reception, FSR, condition is met; and [0255] determine whether to operate a second signal in a radio resource Rr starting at a time T**2** based at least in part on whether the FSR condition is met. [0256] Example 2. The WD of Example 1, wherein the FSR condition includes one of reception of at least N number of a first signal (S**1**) and at least N number of S**1** is available at the WD during a time period (ΔT) before T**2** or between time instances T**1** and T**2**; where ΔT=T**2**−T**1** and T**1**<T**2**. [0257] Example 3. The WD of Example 1, wherein, when the FSR condition is fulfilled, then the processing circuitry is further configured to postpone operation of the second signal. [0258] Example 4. A method implemented in a wireless device (WD), the method comprising: [0259] determining whether a first signal reception, FSR, condition is met; and [0260] determining whether to operate a second signal in a radio resource Rr starting at a time T**2** based at least in part on whether the FSR condition is met. [0261] Example 5. The method of Example 4, wherein the FSR condition includes one of reception of at least N number of a first signal (S**1**) and at least N number of S**1** is available at the WD during a time period (ΔT) before T**2** or between time instances T**1** and T**2**; where ΔT=T**2**−T**1**

and T**1**<T**2**. [0262] Example 6. The method of Example 4, wherein, when the FSR condition is fulfilled, further comprising postponing operation of the second signal.

[0263] As will be appreciated by one of skill in the art, the concepts described herein may be embodied as a method, data processing system, computer program product and/or computer storage media storing an executable computer program. Accordingly, the concepts described herein may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects all generally referred to herein as a "circuit" or "module." Any process, step, action and/or functionality described herein may be performed by, and/or associated to, a corresponding module, which may be implemented in software and/or firmware and/or hardware. Furthermore, the disclosure may take the form of a computer program product on a tangible computer usable storage medium having computer program code embodied in the medium that may be executed by a computer. Any suitable tangible computer readable medium may be utilized including hard disks, CD-ROMs, electronic storage devices, optical storage devices, or magnetic storage devices.

[0264] Some embodiments are described herein with reference to flowchart illustrations and/or block diagrams of methods, systems and computer program products. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, may be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer (to thereby create a special purpose computer), special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0265] These computer program instructions may also be stored in a computer readable memory or storage medium that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer readable memory produce an article of manufacture including instruction means which implement the function/act specified in the flowchart and/or block diagram block or blocks.

[0266] The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0267] It is to be understood that the functions/acts noted in the blocks may occur out of the order noted in the operational illustrations. For example, two blocks shown in succession may in fact be executed substantially concurrently or the blocks may sometimes be executed in the reverse order, depending upon the functionality/acts involved. Although some of the diagrams include arrows on communication paths to show a primary direction of communication, it is to be understood that communication may occur in the opposite direction to the depicted arrows.

[0268] Computer program code for carrying out operations of the concepts described herein may be written in an object oriented programming language such as Python, Java® or C++. However, the computer program code for carrying out operations of the disclosure may also be written in conventional procedural programming languages, such as the "C" programming language. The program code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer. In the latter scenario, the remote computer may be connected to the user's computer through a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an

Internet Service Provider).
[0269] Many different embodiments have been disclosed herein, in connection with the above description and the drawings. It will be understood that it would be unduly repetitious and obfuscating to literally describe and illustrate every combination and subcombination of these embodiments. Accordingly, all embodiments may be combined in any way and/or combination, and the present specification, including the drawings, shall be construed to constitute a complete written description of all combinations and subcombinations of the embodiments described herein, and of the manner and process of making and using them, and shall support claims to any such combination or subcombination.
[0270] Abbreviations that may be used in the preceding description include: [0271] AFC Automatic Frequency Correction [0272] AGC Automatic Gain Control [0273] C-DRX Connected mode DRX [0274] CG Configured Grant [0275] CSI-RS Channel State Information Reference Signal [0276] DCI Downlink Control Information [0277] DL Downlink [0278] DMRS Demodulation Reference Signal [0279] DRX Discontinuous Reception [0280] eDRX Enhanced DRX [0281] FD-FDD Full-Duplex Frequency Division Duplex [0282] gNB Next generation Node B [0283] HD-FDD Half-Duplex Frequency Division Duplex [0284] MAC Medium Access Control [0285] PBCH Physical Broadcast Channel [0286] PDCCH Physical Downlink Control Channel [0287] PO Paging Occasion [0288] PRACH Physical Random Access Channel [0289] PRS Positioning Reference Signal [0290] PUSCH Physical Uplink Shared Channel [0291] RA Random Access [0292] RACH Random access channel [0293] RAR Random Access Response [0294] RedCap Reduced Capability [0295] RF Radio Frequency [0296] RO Random access channel occasion [0297] RRC Radio Resource Control [0298] RSRP Received Signal Received Power [0299] SCS Subcarrier Spacing [0300] SFN System Frame Number [0301] SIB System Information Block [0302] SR Scheduling Request [0303] SRS Sounding Reference Signal [0304] SDT Small Data Transmission [0305] SSB SS/PBCH block [0306] SS/PBCH block Synchronization signal and PBCH block [0307] TA Timing Advance [0308] TDD Time Division Duplex [0309] TRS Tracking Reference Signal [0310] UE User equipment [0311] UL Uplink [0312] WD Wireless Device
[0313] It will be appreciated by persons skilled in the art that the embodiments described herein are not limited to what has been particularly shown and described herein above. In addition, unless mention was made above to the contrary, it should be noted that all of the accompanying drawings are not to scale. A variety of modifications and variations are possible in light of the above teachings without departing from the scope of the following claims.

Claims

1. A wireless device, WD, configured to communicate with a network node in a half-duplex frequency division duplex, HD-FDD, mode, the WD comprising processing circuitry configured to: determine whether a first signal reception, FSR, condition is met, the FSR condition including one of receipt and availability of at least N reference signals during a time interval ΔT ending at a time T**2**, N being an integer greater than zero; and provided that the FSR condition is met, receive a paging signal on a paging resource at the time T**2**.
2. The WD of claim 1, wherein the processing circuitry is further configured to prioritize downlink reception over uplink transmission during the time interval ΔT.
3. The WD of claim 1, wherein the processing circuitry is further configured to prioritize reception of the at least N reference signals over transmission of a random access.
4.-**6**. (canceled)
7. The WD of claim 1, wherein the processing circuitry is further configured to prioritize downlink reception of the at least N reference signals to enable synchronization between the WD and the network node prior to a paging occasion that starts at the time T**2**.
8. The WD of claim 1, wherein the at least N reference signals have a bandwidth exceeding a first

threshold.
9. The WD of claim 1, wherein the at least N2 reference signals during the time interval ΔT that have a bandwidth that falls below a second threshold, N2 being an integer greater than 1.
10.-**12**. (canceled)
13. The WD of claim 1, wherein, when the FSR condition is not met, the processing circuitry is further configured to one of postpone, defer and delay receiving the paging signal.
14. The WD of claim 1, wherein, when the FSR condition is not met, the processing circuitry is further configured to one of postpone, defer and delay receiving the paging signal until the FSR condition is met.
15. (canceled)
16. (canceled)
17. The WD of claim 1, wherein, when the WD is in a low-activity radio resource control, RRC state, the processing circuitry is further configured to re-synchronize with the network node and to perform automatic gain control during the time interval ΔT.
18. The WD of claim 1, wherein ΔT is determined based at least in part on one of a synchronization status of the WD, a discontinuous reception time, and a reference signal transmission periodicity.
19. (canceled)
20. A method in a wireless device, WD, configured to communicate with a network node in a half-duplex frequency division duplex, HD-FDD, mode, the method comprising: determining whether a first signal reception, FSR, condition is met, the FSR condition including one of receipt and availability of at least N reference signals during a time interval ΔT ending at a time T**2**, N being an integer greater than zero; and provided that the FSR condition is met, a receiving paging signal on a paging resource at the time T**2**.
21. The method of claim 20, further comprising prioritizing downlink reception over uplink transmission during the time interval ΔT.
22. The method of claim 20, further comprising prioritizing reception of the at least N reference signals over transmission of a random access.
23.-**25**. (canceled)
26. The method of claim 20, further comprising, prioritizing downlink reception of the at least N reference signals to enable synchronization between the WD and the network node prior to a paging occasion that starts at the time T**2**.
27. The method of claim 20, wherein the FSR condition includes receiving at least N1 number of reference signals during the time interval ΔT that have a bandwidth exceeding a first threshold.
28. The method of claim 20, wherein the at least N2 reference signals during the time interval ΔT that have a bandwidth that falls below a second threshold, N2 being an integer greater than 1.
29.-**31**. (canceled)
32. The method of claim 20, further comprising, when the FSR condition is not met, one of postponing, deferring and delaying receiving the paging signal.
33. The method of claim 20, further comprising, when the FSR condition is not met, one of postponing, deferring and delaying operating the further signal until the FSR condition is met.
34. (canceled)
35. (canceled)
36. The method of claim 20, wherein, when the WD is in a low-activity radio resource control, RRC state, configuring the WD to re-synchronize with the network node and to perform automatic gain control during the time interval ΔT.
37. The method of claim 20, wherein ΔT is determined based at least in part on one of a synchronization status of the WD, a discontinuous reception time, and a reference signal transmission periodicity.
38.-**48**. (canceled)