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GB 2559382 B

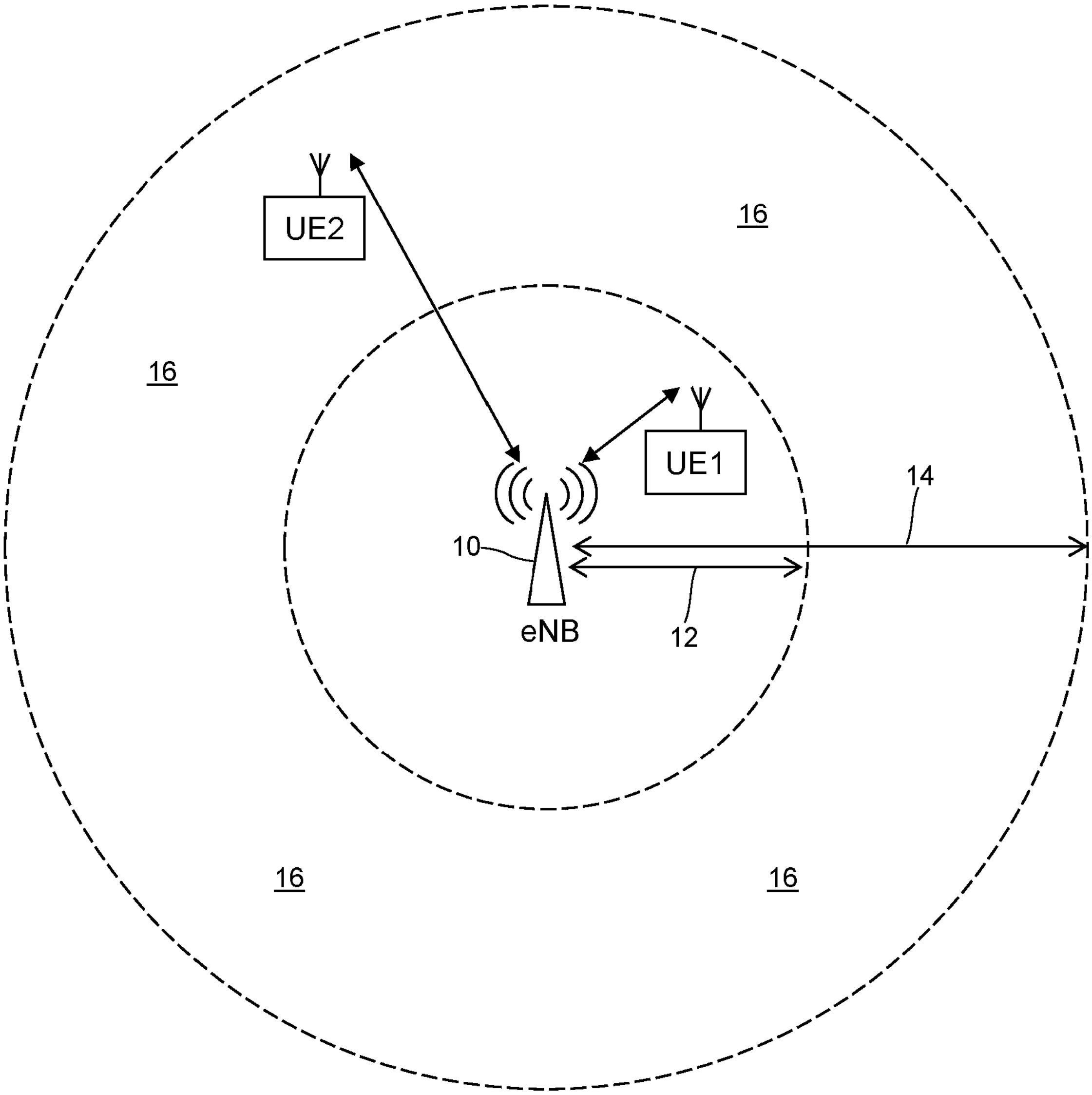

Fig. 1

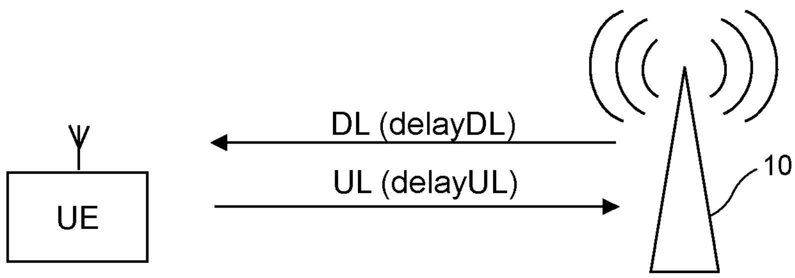

Fig. 2

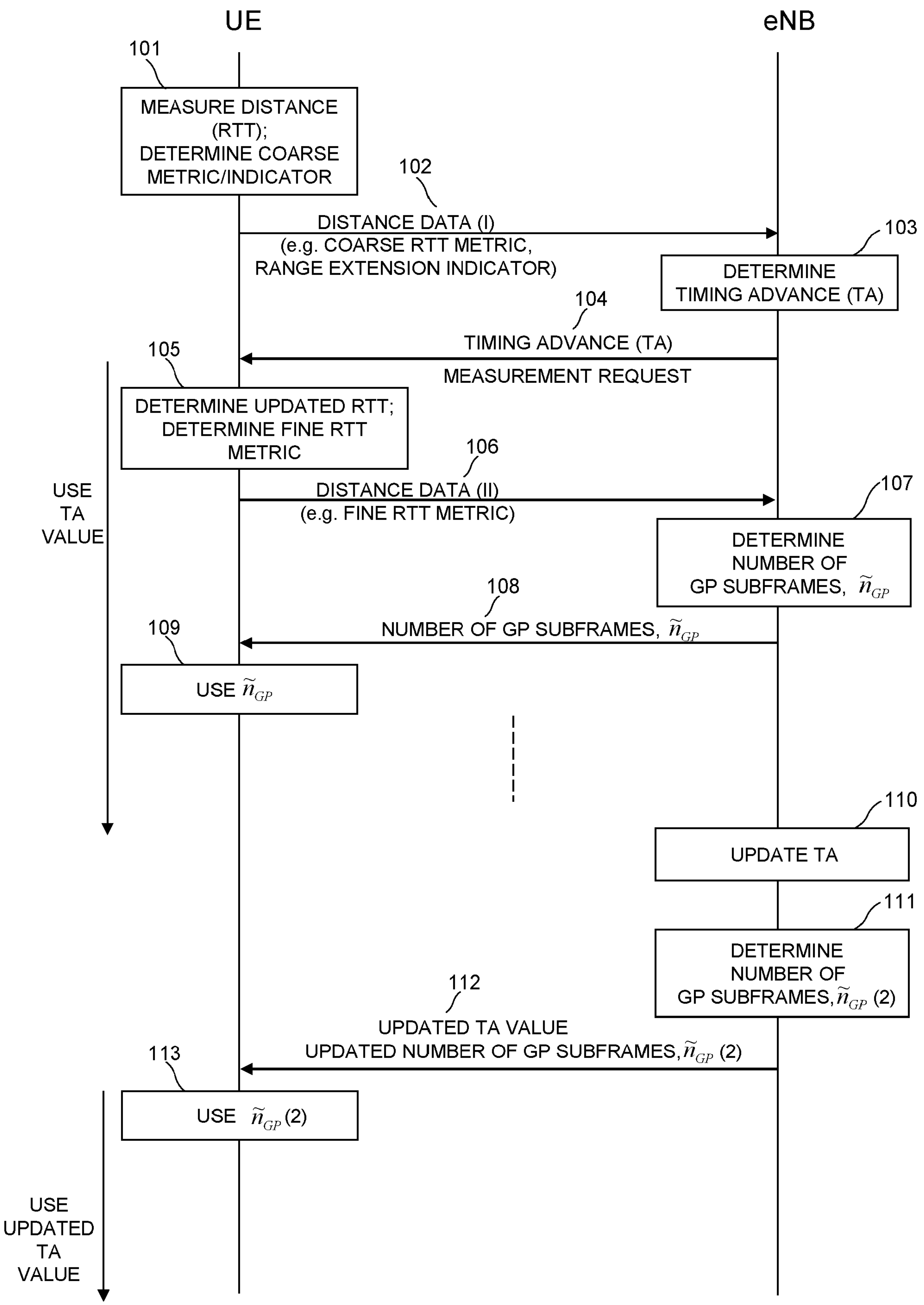
UE
eNB
101
MEASURE DISTANCE (RTT); DETERMINE COARSE METRIC/INDICATOR
102
DISTANCE DATA (I)
(e.g. COARSE RTT METRIC, RANGE EXTENSION INDICATOR)
103
DETERMINE TIMING ADVANCE (TA)
104
TIMING ADVANCE (TA)
MEASUREMENT REQUEST
105
DETERMINE UPDATED RTT; DETERMINE FINE RTT METRIC
106
DISTANCE DATA (II)
(e.g. FINE RTT METRIC)
USE TA VALUE
107
DETERMINE NUMBER OF GP SUBFRAMES, $\tilde{n}_{GP}$
108
NUMBER OF GP SUBFRAMES, $\tilde{n}_{GP}$
109
USE $\tilde{n}_{GP}$
110
UPDATE TA
111
DETERMINE NUMBER OF GP SUBFRAMES, $\tilde{n}_{GP}$ (2)
112
UPDATED TA VALUE
UPDATED NUMBER OF GP SUBFRAMES, $\tilde{n}_{GP}$ (2)
113
USE $\tilde{n}_{GP}$ (2)
USE UPDATED TA VALUE

Fig. 3

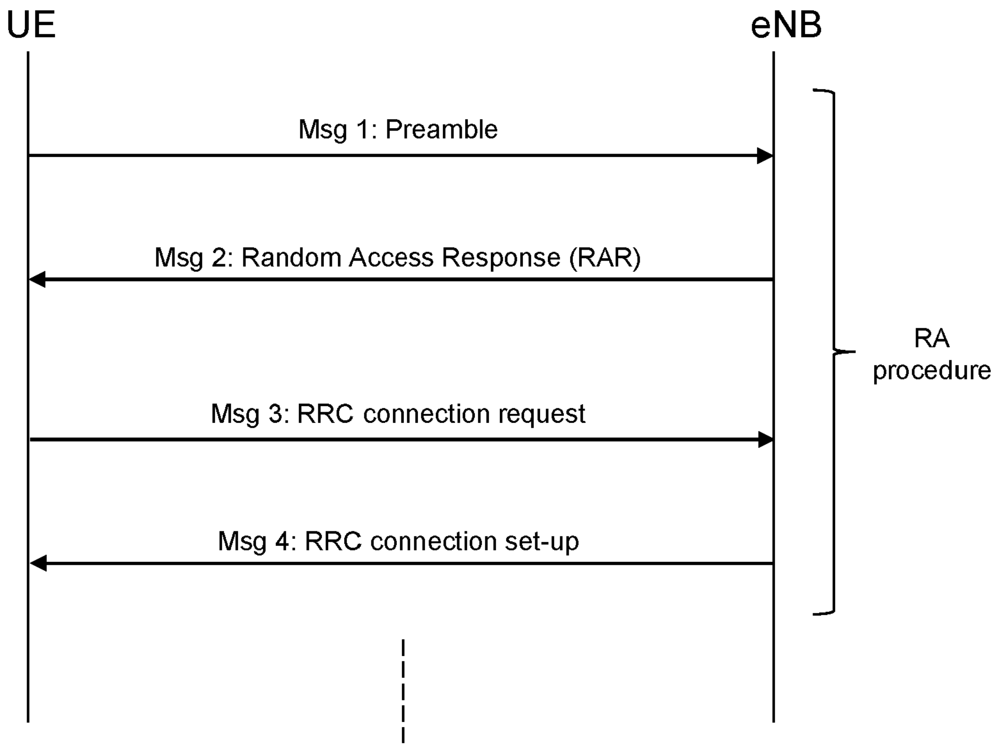
UE
eNB
Msg 1: Preamble
Msg 2: Random Access Response (RAR)
Msg 3: RRC connection request
Msg 4: RRC connection set-up
RA
procedure

Fig. 4

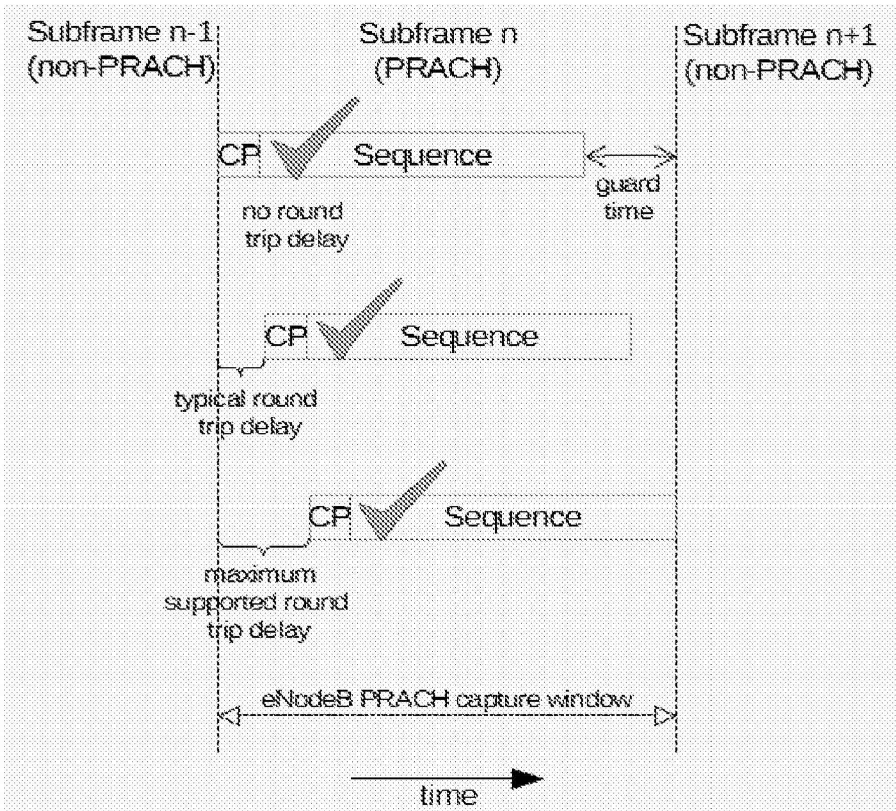
Subframe n-1
(non-PRACH)
Subframe n
(PRACH)
Subframe n+1
(non-PRACH)
CP
Sequence
guard
time
no round
trip delay
CP
Sequence
typical round
trip delay
CP
Sequence
maximum
supported round
trip delay
eNodeB PRACH capture window
time

Fig. 5

Maximum coverage range (km)	Range enhancement (%)	N_{GP}	n_{GP}
150	50%	1	{0, 1}
300	200%	2	{0, 1, 2}
450	350%	3	{0, 1, 2, 3}

Fig. 6

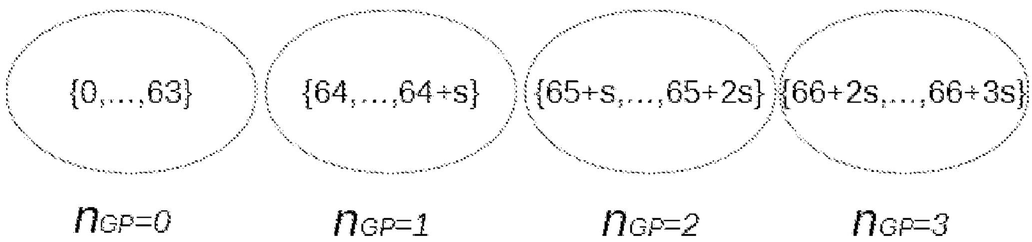

Fig. 7

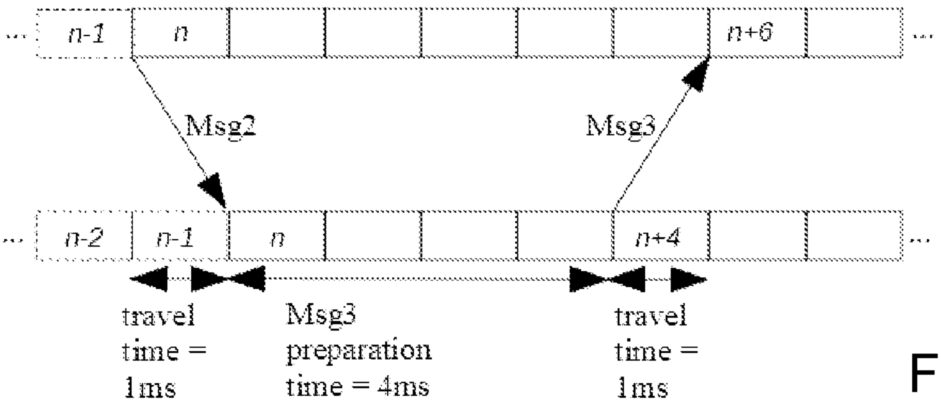

Fig. 8

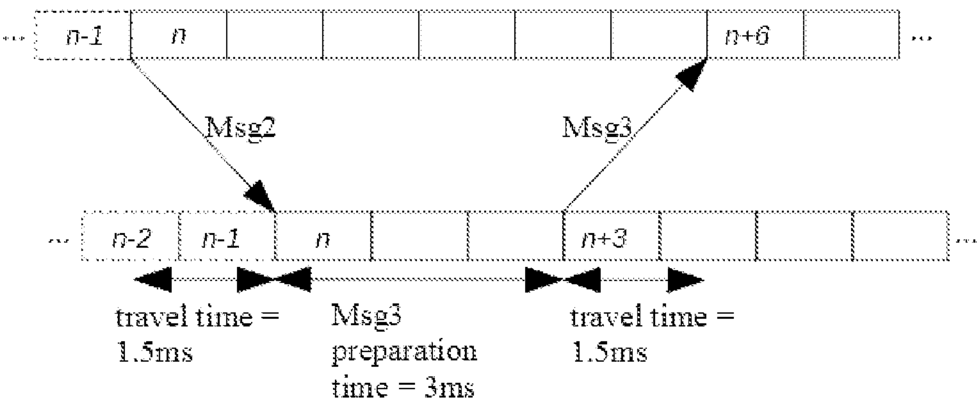

Fig. 9

```
-- ASN1START

RRCConnectionRequest ::=            SEQUENCE {
    criticalExtensions                  CHOICE {
        rrcConnectionRequest-r8             RRCConnectionRequest-r8-IEs,
        criticalExtensionsFuture            SEQUENCE {}
    }
}

RRCConnectionRequest-r8-IEs ::=     SEQUENCE {
    ue-Identity                         InitialUE-Identity,
    establishmentCause                  EstablishmentCause,
    spare                               BIT STRING (SIZE (1))
}

InitialUE-Identity ::=              CHOICE {
    s-TMSI                              S-TMSI,
    randomValue                         BIT STRING (SIZE (40))
}

EstablishmentCause ::=              ENUMERATED {
                                        emergency, highPriorityAccess, mt-Access, mo-
Signalling,
                                        mo-Data, delayTolerantAccess-v1020, mo-VoiceCall-
v1280, spare1}

CPE-Capability-Entry-r14     ::= SEQUENCE {
    numberOfGP-Subframes                INTEGER(0..2)                   OPTIONAL
}

-- ASN1STOP
```

Fig. 10

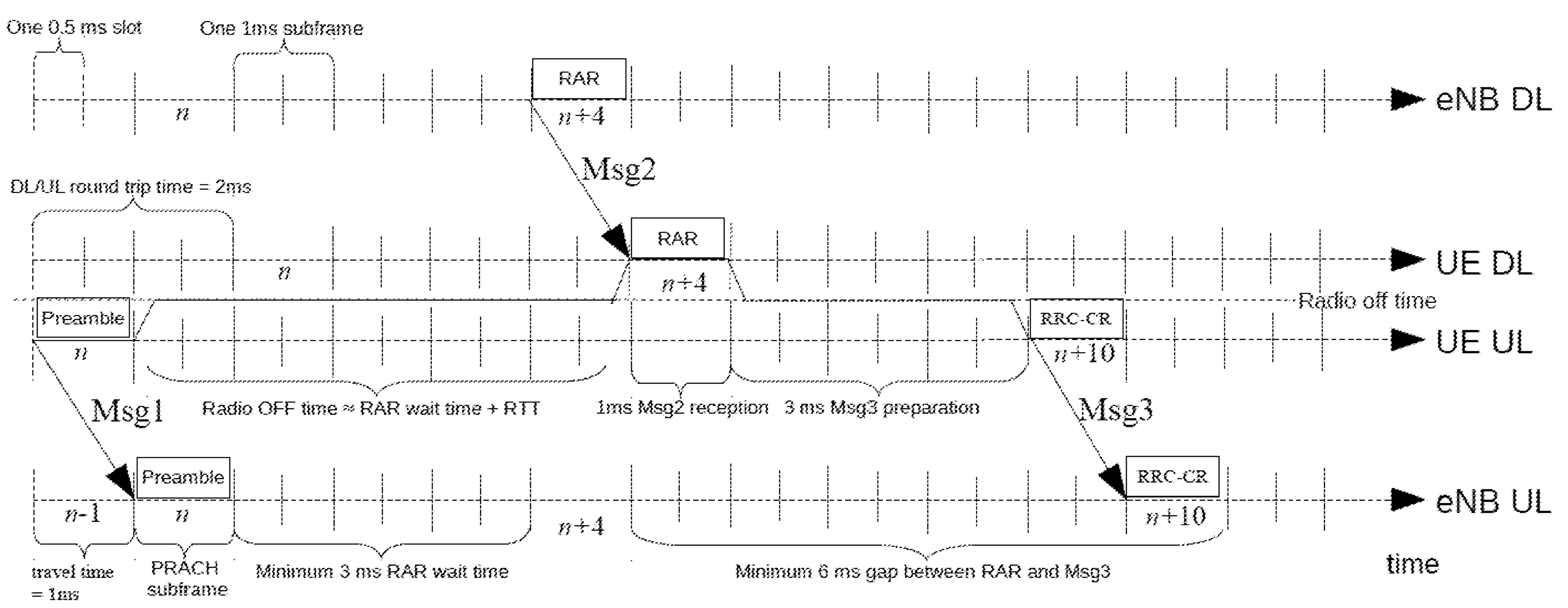
One 0.5 ms slot
One 1ms subframe
RAR
n+4
n
eNB DL
Msg2
DL/UL round trip time = 2ms
RAR
n+4
n
UE DL
Radio off time
Preamble
n
RRC-CR
n+10
UE UL
Msg1
Radio OFF time ≈ RAR wait time + RTT
1ms Msg2 reception
3 ms Msg3 preparation
Msg3
Preamble
RRC-CR
n-1
n
n+4
n+10
eNB UL
travel time = 1ms
PRACH subframe
Minimum 3 ms RAR wait time
Minimum 6 ms gap between RAR and Msg3
time

Fig. 11

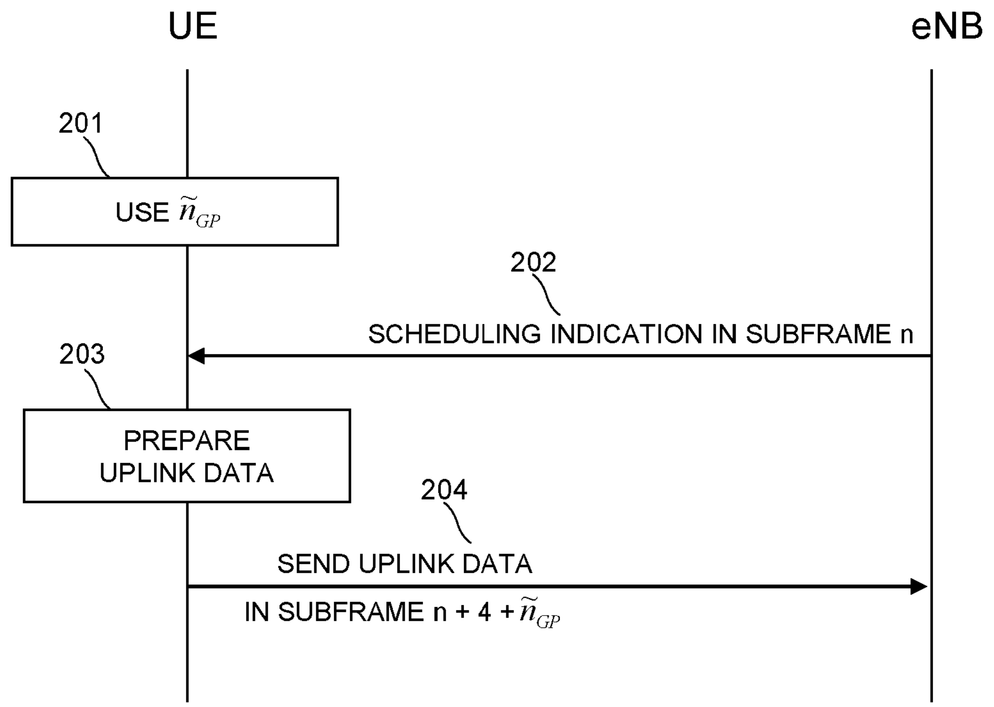

Fig. 12

TDD UL /DL Config	subframe number *n*																													
	0			1			2			3			4			5			6			7			8			9		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
0	D	D	D	G	G	G	U	G	G	U	U	G	U	U	U	D	D	D	G	G	G	U	G	G	U	U	G	U	U	U
1	D	D	D	G	G	G	U	G	G	U	U	G	D	D	D	D	D	D	G	G	G	U	G	G	U	U	G	D	D	D
2	D	D	D	G	G	G	U	G	G	D	D	D	D	D	D	D	D	D	G	G	G	U	G	G	D	D	D	D	D	D
3	D	D	D	G	G	G	U	G	G	U	U	G	U	U	U	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
4	D	D	D	G	G	G	U	G	G	U	U	G	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
5	D	D	D	G	G	G	U	G	G	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
6	D	D	D	G	G	G	U	G	G	U	U	G	U	U	U	D	D	D	G	G	G	U	G	G	U	U	G	D	D	D

Fig. 13

TDD UL/DL Configuration	subframe number *n*									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	4 (D)	6 (S)	(U)	(U)	(U)	4 (D)	6 (S)	(U)	(U)	(U)
1	(D)	6 (S)	(U)	(U)	4 (D)	(D)	6 (S)	(U)	(U)	4 (D)
2	(D)	(S)	(U)	4 (D)	(D)	(D)	(S)	(U)	4 (D)	(D)
3	4 (D)	(S)	(U)	(U)	(U)	(D)	(S)	(D)	4 (D)	4 (D)
4	(D)	(S)	(U)	(U)	(D)	(D)	(S)	(D)	4 (D)	4 (D)
5	(D)	(S)	(U)	(D)	(D)	(D)	(S)	(D)	4 (D)	(D)
6	7 (D)	7 (S)	(U)	(U)	(U)	7 (D)	7 (S)	(U)	(U)	5 (D)

Fig. 14

TDD UL/DL Configuration	subframe number *n*									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	7 (D)	7 (SG)	(U)	(U)	(U)	7 (D)	7 (SG)	(U)	(U)	(U)
1	7 (D)	7 (SG)	(U)	(U)	8 (D)	8 (D)	(SG)	(U)	(U)	(D)
2	7 (D)	(SG)	(U)	(D)	(D)	7 (D)	(SG)	(U)	(D)	(D)
3	(D)	(SG)	(U)	(U)	(U)	(D)	(D)	5 (D)	5 (D)	5 (D)
4	(D)	(SG)	(U)	(U)	(D)	(D)	(D)	5 (D)	5 (D)	(D)
5	(D)	(SG)	(U)	(D)	(D)	(D)	(D)	5 (D)	(D)	(D)
6	7 (D)	7 (SG)	(U)	(U)	(U)	7 (D)	7 (SG)	(U)	(U)	5 (D)

Fig. 15

TDD UL/DL Configuration	subframe number *n*									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	8 (D)	8 (SG)	(ULG)	(U)	(U)	8 (D)	8 (SG)	(ULG)	(U)	(U)
1	8 (D)	(SG)	(ULG)	(U)	(D)	8 (D)	(SG)	(ULG)	(U)	(D)
2 (X)	(D)	(SG)	(ULG)	(D)	(D)	(D)	(SG)	(ULG)	(D)	(D)
3	(D)	(SG)	(ULG)	(U)	(U)	(D)	(D)	6 (D)	6 (D)	(D)
4	(D)	(SG)	(ULG)	(U)	(D)	(D)	(D)	6 (D)	(D)	(D)
5 (X)	(D)	(SG)	(ULG)	(D)	(D)	(D)	(D)	(D)	(D)	(D)
6	8 (D)	(SG)	(ULG)	(U)	(U)	8 (D)	(SG)	7 (ULG)	(U)	(D)

Fig. 16

TDD UL/DL Configuration	subframe number *n*									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	9 (D)	(SG)	(ULG)	(ULG)	(U)	9 (D)	(SG)	(ULG)	(ULG)	(U)
1 (X)	(D)	(SG)	(ULG)	(ULG)	(D)	(D)	(SG)	(ULG)	(ULG)	(D)
2 (X)	(D)	(SG)	(ULG)	(D)	(D)	(D)	(SG)	(ULG)	(D)	(D)
3	(D)	(SG)	(ULG)	(ULG)	(U)	(D)	(D)	7 (D)	(D)	(D)
4 (X)	(D)	(SG)	(ULG)	(ULG)	(D)	(D)	(D)	(D)	(D)	(D)
5 (X)	(D)	(SG)	(ULG)	(D)	(D)	(D)	(D)	(D)	(D)	(D)
6	(D)	(SG)	(ULG)	(ULG)	(U)	9 (D)	(SG)	(ULG)	(ULG)	(D)

Fig. 17

TDD UL/DL Configuration	subframe number *n*									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	(D)	(S)	6 (U)	(U)	4 (U)	(D)	(S)	6 (U)	(U)	4 (U)
1	(D)	(S)	7, 6 (U)	4 (U)	(D)	(D)	(S)	7, 6 (U)	4 (U)	(D)
2	(D)	(S)	8, 7, 4, 6 (U)	(D)	(D)	(D)	(S)	8, 7, 4, 6 (U)	(D)	(D)
3	(D)	(S)	7, 6, 11 (U)	6, 5 (U)	5, 4 (U)	(D)	(S)	(D)	(D)	(D)
4	(D)	(S)	12, 8, 7, 11 (U)	6, 5, 4, 7 (U)	(D)	(D)	(S)	(D)	(D)	(D)
5	(D)	(S)	13, 12, 9, 8, 7, 5, 4, 11, 6 (U)	(D)	(D)	(D)	(S)	(D)	(D)	(D)
6	(D)	(S)	7 (U)	7 (U)	5 (U)	(D)	(S)	7 (U)	7 (U)	(D)

Fig. 18

TDD UL/DL Configuration	subframe number *n*									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	(D)	(SG)	7 (U)	(U)	8 (U)	(D)	(SG)	7 (U)	(U)	8 (U)
1	(D)	(SG)	8, 7 (U)	7 (U)	(D)	(D)	(SG)	8, 7 (U)	7 (U)	(D)
2	(D)	(SG)	9, 8, 7, 6 (U)	(D)	(D)	(D)	(SG)	9, 8, 7, 6 (U)	(D)	(D)
3	(D)	(SG)	12, 11 (U)	8, 7, 6 (U)	6, 5	(D)	(D)	(D)	(D)	(D)
4	(D)	(SG)	12, 8, 13, 11 (U)	5, 6, 8, 7 (U)	(D)	(D)	(D)	(D)	(D)	(D)
5	(D)	(SG)	13, 12, 9, 8, 7, 5, 14, 11, 6 (U)	(D)	(D)	(D)	(D)	(D)	(D)	(D)
6	(D)	(SG)	7 (U)	7 (U)	5	(D)	(SG)	7 (U)	7 (U)	(D)

Fig. 19

TDD UL/DL Configuration	subframe number *n*									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	(D)	(SG)	(ULG)	8 (U)	8 (U)	(D)	(SG)	(ULG)	8 (U)	8 (U)
1	(D)	(SG)	(ULG)	7, 8, 9 (U)	(D)	(D)	(SG)	(ULG)	7, 8, 9 (U)	(D)
2 (X)	(D)	(SG)	(ULG)		(D)	(D)	(SG)	(ULG)	(D)	(D)
3	(D)	(SG)	(ULG)	12, 13, 14 (U)	9, 8, 7, 6 (U)	(D)	(D)	(D)	(D)	(D)
4	(D)	(SG)	(ULG)	15, 14, 13, 12, 9, 8, 7, 6 (U)	(D)	(D)	(D)	(D)	(D)	(D)
5 (X)	(D)	(SG)	(ULG)		(D)	(D)	(D)	(D)	(D)	(D)
6	(D)	(SG)	(ULG)	12, 8 (U)	8 (U)	(D)	(SG)	(ULG)	9, 8 (U)	(D)

Fig. 20

TDD UL/DL Configuration	subframe number *n*									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	(D)	(SG)	(ULG)	(ULG)	9, 8 (U)	(D)	(SG)	(ULG)	(ULG)	9, 8 (U)
1 (X)	(D)	(SG)	(ULG)	(ULG)	(D)	(D)	(SG)	(ULG)	(ULG)	(D)
2 (X)	(D)	(SG)	(ULG)	(D)	(D)	(D)	(SG)	(ULG)	(D)	(D)
3	(D)	(SG)	(ULG)	(ULG)	9, 8, 7, 13, 14, 15, 16 (U)	(D)	(D)	(D)	(D)	(D)
4 (X)	(D)	(SG)	(ULG)	(ULG)	(D)	(D)	(D)	(D)	(D)	(D)
5 (X)	(D)	(SG)	(ULG)	(ULG)	(D)	(D)	(D)	(D)	(D)	(D)
6	(D)	(SG)	(ULG)		8, 9, 13, 14, 15 (U)	(D)	(SG)	(ULG)	(ULG)	(D)

Fig. 21

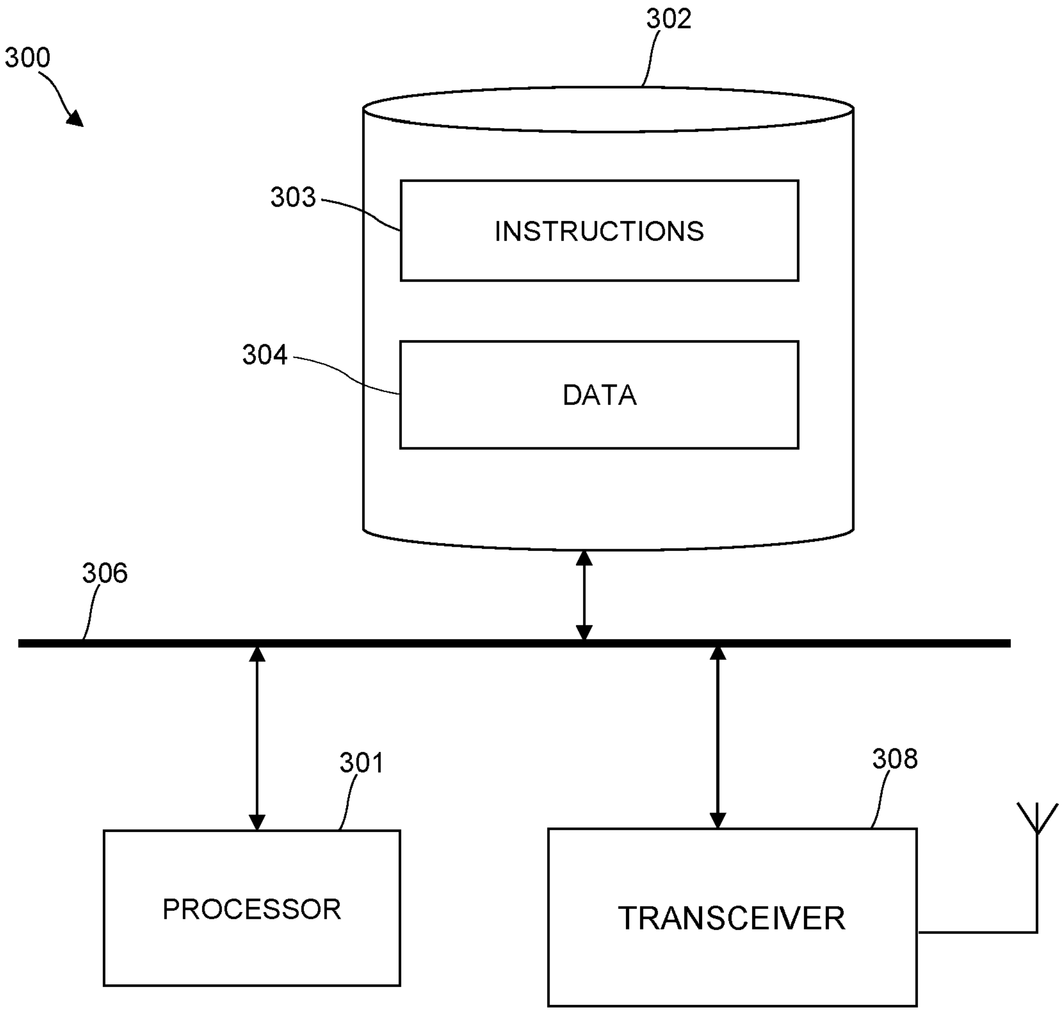
300
302
303
INSTRUCTIONS
304
DATA
306
301
308
PROCESSOR
TRANSCEIVER

Fig. 22

SYSTEMS AND METHODS FOR CELL RANGE EXTENSION

TECHNICAL FIELD

[0001] The present disclosure relates to extending the coverage of a wireless base station in a wireless communication system.

BACKGROUND

[0002] Long-Term Evolution (LTE) is a wireless communication technology developed by the 3rd Generation Partnership Project (3GPP). The current LTE standards (up to Release 13) support a maximum cell radius of around 107km, which corresponds to a Maximum Coupling Loss (MCL) defined since Release 8. LTE technology is now expanding its original use to additional wireless communication areas like Machine Type Communications (MTC), Internet of Things (IoT) and air-to-ground communication. These technologies potentially require extending the covering range.

[0003] Improvements have made it possible for wireless user equipments (UE) to operate with a higher MCL, and therefore the capability of operating at a longer range from a base station or access point. For example, a Coverage Enhancement (CE) UE which has the capability of increasing the MCL by ~15 dB will be able to detect and synchronise to an LTE cell even if it is located at a distance of approximately four times the current maximum cell radius.

[0004] However, other aspects of current LTE standards do not allow UEs to operate in cells of this increased size.

[0005] The examples described below are not limited to implementations which solve any or all of the disadvantages of known systems.

SUMMARY

[0001] There is provided method of supporting extended range communication between a wireless base station and a first wireless device comprising, at the wireless base station:

receiving information from the first wireless device, the information indicative of a distance or a time delay between the wireless base station and the first wireless device;

determining, based on the received information, if the first wireless device is located beyond a first range; and

if it is determined that the first wireless device is located beyond the first range:

determining a first guard period to be used to communicate with the first wireless device, wherein the first guard period is longer than a second guard period used to communicate with a wireless device within the first range; and

sending an indication of the first guard period to the first wireless device.

[0002] Optionally, determining a first guard period comprises determining an integer number of subframes for the first guard period.

[0003] Optionally, the first guard period is selected from a plurality of different values, each value being an integer number of subframes.

[0004] Optionally, the method comprises: communicating with the first wireless device using the first guard period; and communicating with a second wireless device using the second guard period, wherein the second wireless device is located within the first range.

[0005] Optionally, the information received from the first wireless device comprises an indication of a round trip time between the wireless base station and the wireless device.

[0006] Optionally, the indication of round trip time is received on an uplink random access channel.

[0007] Optionally, the indication of round trip time indicates the round trip time as an integer number of subframes.

[0008] Optionally, the indication of round trip time is signalled by a preamble sequence which is different to preamble sequences used when the wireless device is located within the first range.

[0009] Optionally, the indication of round trip time is received in a connection request message on an uplink Physical Random Access Channel, PRACH.

[0010] Optionally, the information received from the first wireless device comprises a flag indicating that the first wireless device is located beyond the first range.

[0011] Optionally, the information received from the first wireless device comprises a first indication of round trip time at a coarse granularity and a second indication of round trip time at a finer granularity than the first indication.

[0012] Optionally, the second indication of round trip time is received after a timing advance has been sent to the wireless device.

[0013] Optionally, determining a first guard period and sending an updated indication of the first guard period to the first wireless device are repeated during a connection with the first wireless device.

[0014] Optionally, the first guard period is used for TDD or HD-FDD operation, the method comprising: using the first guard period between downlink and uplink subframes.

[0015] Optionally, the method comprises: sending a scheduling indication during downlink subframe n to schedule an uplink data transmission; determining an expected uplink subframe to receive the data based on n and the first guard period.

[0016] Optionally, the method comprises: sending downlink data during a downlink subframe n; and determining an expected uplink subframe to receive a hybrid automatic repeat request acknowledgement, HARQ-ACK, based on n and the first guard period.

[0017] Optionally, determining the first guard period comprises calculating:

$$\tilde{n}_{GP} = \begin{cases} \left\lceil \tilde{T}_{RTT}(s) \big/ 1000(ms) \right\rceil, & \tilde{T}_{RTT} > T_{GP} \\ 0, & 0 \le \tilde{T}_{RTT} \le T_{GP} \end{cases}$$

where: $\tilde{n}_{GP}$ is an integer number of guard period subframes; T_{GP} is the length of the guard period in a preamble format for a non-extended cell; $\tilde{T}_{RTT}$ is round trip delay received from the wireless device.

[0018] There is also provided a method of supporting extended range communication between a wireless device and a wireless base station comprising, at the wireless device:

determining a measurement indicative of a distance between the wireless device and the wireless base station;

determining data indicative of the distance based on the measurement;

sending the data to the wireless base station;

receiving an indication of a guard period to be used when communicating with the wireless base station, wherein the guard period has a first value when the wireless device is located beyond a first range of the wireless base station, and the guard period has a second value when the wireless device is located within the first range of the wireless base station, wherein the second value is smaller than the first value.

[0019] Optionally, the data comprises an indication of a round trip time between the wireless base station and the wireless device.

[0020] Optionally, the indication of round trip time is sent on an uplink random access channel.

[0021] Optionally, the indication of round trip time indicates the round trip time as an integer number of subframes.

[0022] Optionally, there are preamble sequences corresponding to different integer numbers of subframes, and the method comprises selecting and using a preamble sequence for the round trip time.

[0023] Optionally, the indication of round trip time is sent in a connection request message on an uplink Physical Random Access Channel, PRACH.

[0024] Optionally, the method comprises: determining, based on the data indicative of the distance, if the first wireless device is located beyond the first range; and sending an identifier which indicates if the first wireless device is located beyond the first range.

[0025] Optionally, the information sent from the first wireless device comprises a first indication of round trip time at a coarse granularity and a second indication of round trip time at a finer granularity than the first indication.

[0026] Optionally, the second indication of round trip time is calculated as:

$$\tilde{T}_{RTT} = \left\lceil T_{RTT} / G_{RTT} \right\rceil$$

where: $\tilde{T}_{RTT}$ = fine round trip time metric; T_{RTT} = estimated round trip time; G_{RTT} = a granularity known to the wireless base station and the wireless device.

[0027] Optionally, the method comprises: receiving a timing advance from the wireless base station; updating a round trip time; and sending the second indication of round trip time based on the updated round trip time.

[0028] Optionally, the method comprises receiving an updated indication of a guard period during a connection with the wireless base station.

[0029] Optionally, the indication of the guard period is an integer number of subframes.

[0030] Optionally, the integer number of subframes is calculated by:

$$n_{GP} = \begin{cases} \left\lceil T_{RTT}(s) \big/ 1000(ms) \right\rceil, & T_{RTT} > T_{GP} \\ 0, & 0 \le T_{RTT} \le T_{GP} \end{cases}$$

where: n_{GP} is an integer number of subframes; T_{GP} is the length of the guard period in a preamble format for a non-extended cell; T_{RTT} is round trip delay received from the wireless device.

[0031] Optionally, the first guard period is used for TDD or HD-FDD operation, the method comprising: using the first guard period between downlink and uplink subframes.

[0032] Optionally, the method comprises: receiving a scheduling indication during downlink subframe n to schedule an uplink data transmission; determining an uplink subframe to send the data based on n and the guard period.

[0033] Optionally, the method comprises: receiving downlink data during a downlink subframe n; and determining an uplink subframe to send a hybrid automatic repeat request acknowledgement, HARQ-ACK, based on n and the guard period.

[0034] There is also provided a wireless base station configured to perform the method as disclosed or claimed.

[0035] There is also provided a wireless device configured to perform the method as disclosed or claimed.

[0006] At least one example of this disclosure facilitates the establishment and maintenance of a link between a User Equipment (UE) and a LTE cell (eNodeB) when the UE is positioned beyond the network configured cell range. The UE reports a metric which describes the round trip time (RTT) of the link to allow a reliable communication between the UE and eNodeB.

[0007] At least one example of this disclosure minimises, or avoids, adding extra effort to the signal processing of the eNodeB. At least one example of this disclosure does not degrade the spectral efficiency of the communication system. At least one example of this disclosure is backwards compatible with the existing 3GPP standards.

[0008] Examples of this disclosure are applicable to Frequency Division Duplex (FDD), Time Division Duplex (TDD) and Half Duplex FDD (HD-FDD) versions of LTE.

Examples of this disclosure are applicable to normal and/or extended Cyclic Prefix (CP). Examples of this disclosure are applicable to UEs which have coverage enhancement (CE) capabilities including, but not limited to, bandwidth limited/coverage enhancement (BL/CE), machine type communication (MTC), and Narrowband Internet-of-Things (NB-IoT), UEs supporting air-to-ground communication.

[0009] Although examples focus on modifications to the LTE Release 13 architecture, this disclosure can be applied in other synchronous wireless communication systems as typically the evolution of LTE considered in New Radio context.

[0010] The functionality described here can be implemented in hardware, software executed by a processing apparatus, or by a combination of hardware and software. The processing apparatus can comprise a computer, a processor, a state machine, a logic array or any other suitable processing apparatus. The processing apparatus can be a general-purpose processor which executes software to cause the general-purpose processor to perform the required tasks, or the processing apparatus can be dedicated to perform the required functions. Another aspect of the invention provides machine-readable instructions (software) which, when executed by a processor, perform any of the described methods. The machine-readable instructions may be stored on an electronic memory device, hard disk, optical disk or other machine-readable storage medium. The machine-readable medium can be a non-transitory machine-readable medium. The term "non-transitory machine-readable medium" comprises all machine-readable media except for a transitory, propagating signal. The machine-readable instructions can be downloaded to the storage medium via a network connection.

[0011] Examples, embodiments and/or features of any example or embodiment can be combined in any way and/or combination, unless such features are incompatible.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Examples of the invention will be described, by way of example, with reference to the following drawings, in which:

[0013] Figure 1 shows a wireless communication system with a wireless base station serving UEs at different ranges;

[0014] Figure 2 shows an uplink and a downlink between a wireless base station and a UE;

[0015] Figure 3 shows an example method of operation in the network of Figure 1;

[0016] Figure 4 shows an LTE random access procedure;

[0017] Figure 5 shows attempts to transmit within a PRACH receive window;

[0018] Figure 6 shows a table of values used in an example supporting range enhancement;

[0019] Figure 7 shows preamble sequences for signalling a metric value;

[0020] Figure 8 shows messages during the random access procedure with a first round trip time;

[0021] Figure 9 shows messages during the random access procedure with a second round trip time longer than the one in Figure 8;

[0022] Figure 10 shows an example of a message used during the random access procedure;

[0023] Figure 11 shows messages during the random access procedure;

[0024] Figure 12 shows an example of scheduling in a FDD mode;

[0025] Figure 13 shows an example of a modified Frame structure Type 2 with different numbers of guard subframes;

[0026] Figures 14 to 17 show scheduling timing data for modified Frame structure Type 2;

[0027] Figures 18 to 21 show timing data for HARQ-ACK operation with Frame structure Type 2;

[0028] Figure 22 schematically shows example apparatus at a wireless base station or a wireless device.

DETAILED DESCRIPTION

[0029] Examples of the present invention are described below by way of example only. These examples represent the best ways of putting the invention into practice that are currently known to the Applicant although they are not the only ways in which this could be achieved. The description sets forth the functions of the example and the sequence of steps for constructing and operating the example. However, the same or equivalent functions and sequences may be accomplished by different examples.

[0030] Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible.

[0031] Figure 1 schematically shows an example of a wireless communications system with a wireless base station 10 (e.g. wireless base station, wireless access point, eNodeB, eNB) and wireless devices UE1, UE2. A wireless device may also be called a user equipment (UE) or a terminal. The wireless base station 10 defines a coverage area, or cell, with a first radius 12. This first radius can be called the configured cell radius. It may correspond to the maximum cell radius which is permitted by the LTE standards, e.g. 107km. A wireless device UE1 is shown located within the configured cell radius 12. The wireless base station 10 can also be used to serve wireless devices located in region 16, which is outside the first cell radius 12, and within the second cell radius 14. This second radius 14 can be the maximum cell radius. In examples, the second radius may correspond to a cell radius of 50% (150km), 200% (300km) or 350% (450 km) of the first cell radius (100 km). It will be understood that other values are possible. A wireless device UE2 is shown located within region 16.

[0032] In an example of the present invention, the wireless base station 10 can serve wireless devices, such as UE1, located within the first cell radius 12, and can also serve wireless devices, such as UE2, located within the region 16 between first cell radius 12 and the second cell radius 14. The wireless base station 10 continues to serve wireless devices UE1 located within the first cell radius 12 using communication parameters related to the first cell radius. For example, in a TDD or HD-FDD system, UE1 communicates using a guard period for a cell of radius 12. The wireless base station 10 serve wireless devices UE2 located within the region 16 using communication parameters related to the second cell radius 14. For example, in a TDD or HD-FDD system, UE2 communicates using a longer guard period for a cell of radius 14. This allows legacy devices to be served without changes to their operation. It also makes better use of spectral resources. Although two UEs are shown in this example it will be understood that the eNB can serve a much larger number of UEs.

[0033] Figure 2 shows a wireless device UE served by the wireless base station 10. Wireless communication comprises downlink (DL) transmissions from the wireless base station 10 to the UE and uplink (UL) transmissions from the UE to the wireless base station 10. A signal transmitted on the downlink has a propagation delay delayDL. A signal transmitted on the uplink has a propagation delay delayUL. There is a total round trip time of RTT = delayDL + delayUL.

[0034] LTE supports Time Division Duplex (TDD) and Frequency Division Duplex (FDD) operation. LTE also supports Half Duplex Frequency Division Duplex (HD-FDD). In HD-FDD, a device receives on a DL frequency band during a first time period and then transmits on an UL frequency band during a second time period. The device does not simultaneously transmit and receive. In this respect, HD-FDD is like TDD. HD-FDD is suited to low-complexity UEs.

[0035] The propagation delays described above have an impact on operation in TDD and FDD modes. A wireless device operating in a TDD mode cannot simultaneously receive and transmit. The device must wait until it has received a downlink subframe before it can transmit an uplink subframe. LTE provides a guard period between the downlink subframe and the uplink subframe to allow for propagation delays. The guard period is provided as part of a special subframe defined in TS 36.211 at section 4.2, Table 2. LTE defines a number of different special subframe configurations (0, 1, 2,…8) for different cell sizes. The special subframe is always one subframe in length. Conventionally, all UEs within a cell operate with the same special subframe configuration. For example, in the largest supported cell size of 107km, all UEs use a Special Subframe configuration 0, with a guard period of 10 OFDM symbols.

[0036] The guard periods defined in TS 36.211 are not suitable to support a TDD mode at a distance beyond 107km. In examples of the present invention, wireless devices located beyond the first cell radius 12 use a longer guard period. The guard period can be an integer number of subframes in length, e.g. 1, 2 or 3 subframes. The longer guard period allows a downlink subframe to reach the wireless device, and allows the wireless device to transmit an uplink subframe which arrives at the base station synchronously with subframes transmitted by other, closer, devices. A device transmits an uplink subframe with a timing advance to achieve the synchronous operation.

[0037] A wireless device operating in a FDD mode can simultaneously receive and transmit. However, wireless devices are constrained by several time limits. A device which receives a scheduling grant during downlink subframe n should transmit an uplink subframe during subframe n+4. Similarly, a device which receives downlink data during downlink subframe n should transmit a hybrid automatic repeat request acknowledgement, HARQ-ACK, during an uplink subframe n+4. This means that the device has around 3 subframes (3ms) to prepare a response. In larger cells, the round trip time RTT reduces this available time. Therefore, devices located further away from the eNB require a longer period for each of these processes.

[0038] The method uses information received from a wireless device. The information indicates distance between the wireless base station and the wireless device. This allows the base station to select a guard period which is suitable for each of the wireless devices. For example, in Figure 1 the eNB can select a normal guard period for UE1 and an extended guard period for UE2.

[0039] Figure 3 shows an example of a method performed by a wireless device (UE) and a wireless base station (eNB). At block 101 the UE determines distance or propagation delay between the UE and the eNB. Various techniques are possible. In one example, the UE can use measure a signal received from the eNB. By knowing the transmitted power of the signal and the received power, the UE can determine path loss of the signal. Path loss is related to distance and propagation delay. The UE can derive a distance from the path loss by using stored data, such as a look-up table stored at the UE, or data obtained from the eNB or another source. Other techniques of determining distance/delay are Observed Time Difference of Arrival (OTDOA), Uplink Time Difference of Arrival (UTDOA), Enhanced Cell-ID (ECID). Another technique is to use information from a global positioning system receiver such as Global Positioning System (GPS). The UE determines distance between the UE and the base station. The determined distance can be converted into a delay, such as a round trip time (RTT) or a one-way delay (eNB-UE or UE-eNB). The terms “round trip time (RTT)” and “round trip delay (RTD)” refer to the same quantity. An initial estimate of round trip time RTT is calculated as:

$$T_{RTT,init} = 2d/c$$

where: d = distance (e.g. eNB to UE) and c = speed of light.

[0040] RTT is a useful quantity for the UE and the eNB. It represents the time delay the UE will experience when communicating with the eNB. RTT can be used to select a negative time offset for sending a random access attempt to the eNB. The UE can send an RTT metric or, more generally, can send 102 information indicative of the distance.

[0041] It is desirable that the eNB is informed of the delay/distance as early as possible. A first stage of communicating with an eNB is a random access RA procedure. The delay/distance can be signalled to the eNB during the RA procedure. Some possible techniques for signalling the value are described below. The delay/distance can be converted to a metric with a coarse granularity. A convenient granularity is 1 ms (= 1 subframe). The UE can signal a RTT as a number of subframes n_{GP}. This has an advantage of reducing the amount of data which needs to be signalled, and allows an indication of delay/distance to be sent as early as possible. An alternative to signalling a delay/distance value is simply to signal that the UE is located outside the first cell radius (12, Fig. 1). This can require as little as a single data bit (e.g. a flag set to "1" to indicate the UE is outside the first cell radius).

[0042] During the RA procedure, the UE attempts to transmit a signal on an uplink Physical Random Access Channel (PRACH), so that the signal arrives at the eNB within a time window on the PRACH. Optionally, the system can use the same maximum length of PRACH window as defined in LTE Release 13. This has an advantage of not requiring additional spectral resources to support UEs outside the configured cell radius. The UE can use an initial value of RTT, calculated using one of the techniques described above, to time the uplink transmission so that it arrives within the PRACH detection window. A UE may need to make a plurality of attempts with different values of RTT.

[0043] At block 103, the RA procedure determines a timing advance TA for the UE, based on a signal received from the UE during a Physical Random Access Channel (PRACH) window. The TA is a time offset which the UE uses to synchronise with other UEs, so that an uplink transmission from the UE arrives in synchronism with uplink transmissions of other UEs. At block 104 the TA is sent to the UE. The UE starts to use the TA, in combination with any RTT (number of subframes, n_{GP}) it calculated at block 101. The eNB sends a measurement request to the UE.

[0044] At block 105 the UE updates the initial estimate of RTT, $T_{RTT,\ init}$ (calculated at block 101) which was successful in arriving within the PRACH window:

$$T_{RTT} = T_{RTT,init} + TA$$

where: $T_{RTT,init}$ is the initial RTT estimate that the UE used to successfully transmit Msg1;

T_{RTT} is the fine tuning of the RTT by utilizing the received TA value.

[0045] The UE determines another indicator of delay/distance, such as RTT. This indicator represents the delay/distance to a finer degree of granularity than the metric calculated at block 101. The indicator is sent 106 to the eNB. At block 107 the eNB determines a number of guard subframes, $\tilde{n}_{GP}$, required to support the UE using the information received from the UE:

$$\tilde{n}_{GP} = \begin{cases} \left\lceil \tilde{T}_{RTT}(s) \big/ 1000(ms) \right\rceil, & \tilde{T}_{RTT} > T_{GP} \\ 0, & 0 \le \tilde{T}_{RTT} \le T_{GP} \end{cases}$$

where T_{GP} is the length of the guard period in a preamble format for a non-extended cell. If the round trip time is less than T_{GP}, the UE is within the normal range (12, Fig. 1) of the eNB and can operate as normal. If the round trip time is greater than T_{GP}, the UE needs to operate with an additional guard period. This equation defines a ceiling function for round trip times greater than T_{GP}. For example: a RTT of 1.2 ms is rounded up to 2 ms (= 2 subframes); a RTT of 2.2 ms is rounded up to 3 ms (= 3 subframes), and so on.

[0046] At block 108 the number of guard subframes, $\tilde{n}_{GP}$, is sent to the UE. At block 109 the UE receives the value of $\tilde{n}_{GP}$. The UE begins to use the value of $\tilde{n}_{GP}$ during communication with the base station. The value of $\tilde{n}_{GP}$ can be used during one or more of: a number of guard period subframes between downlink and uplink subframes; determining an uplink subframe to send data; determining an uplink subframe to send an acknowledgement (e.g. HARQ-ACK).

[0047] As the distance/delay between the UE and eNB changes, the eNB updates the TA to ensure continued synchronisation. At block 110 the eNB calculates an updated value of TA. The eNB determines if a change is required to the number of guard subframes $\tilde{n}_{GP}$. The new value of TA and an updated value of $\tilde{n}_{GP}$ (if required) is sent 112 to the UE. Both the eNB and UE are now aware of the value of $\tilde{n}_{GP}$ which is needed during the connection. At block 113 the UE uses the updated value of TA and $\tilde{n}_{GP}$.

[0048] Consider an example of a UE on an airplane which is initially 300km away from the eNB. Initially, $\tilde{n}_{GP} = 2$. At some later point, the UE will be close enough to the base station to require a change of $\tilde{n}_{GP} = 1$. When the UE moves inside the "regular" cell radius (12, Fig. 1) the base station can configure $\tilde{n}_{GP} = 0$. Once the UE passes over the eNB and moves away from it, the inverse procedure of increasing the value of $\tilde{n}_{GP}$ can occur, with $\tilde{n}_{GP}$ changing from 0 → 1 → 2. The eNB can notify UEs that it supports range extension by broadcasting an indication within the System Information (SI).

[0049] Some further details will now be described.

Random Access (RA) Procedure

[0050] Figures 4 and 5 show the Random Access (RA) Procedure for establishing a connection between a UE and an eNodeB.

Msg1: The UE selects one of 64 available PRACH preamble sequences and transmits it during one of the predefined uplink PRACH subframes. This sequence has a specific length which is defined by the Preamble configuration (controlled by higher layers). The UE transmits this sequence aiming its detection during the PRACH subframes at the base station, based on the experienced downlink timing. In practice, this signal will be received at the base station after a delay which equals to the RTT. During the PRACH subframes, the eNodeB opens a PRACH preamble detection window where it attempts to detect all 64 sequences though a correlation mechanism. The detection window has a length which not only fits the length of the preamble sequences, but also the maximum RTT that the network has configured. Thus, the total length of the PRACH detection window is: $T_W = T_{CP} + T_{SEQ} + T_{GT}$, where T_{GT} is the guard time which corresponds to the maximum round trip time. UEs located at the cell edge experience the maximum round trip time and their preamble sequences arrive at the very end of the eNodeB detection window. Each Preamble format corresponds to different GT lengths, and consequently, different cell sizes. The minimum cell size is ~14 km (Preamble format 0) and the maximum cell size is ~107 km (Preamble format 3). More details can be found in Section 5.7 of 3GPP TS 36.211. The UE computes a Random Access Radio Network Temporary Identity (RA-RNTI). If UE already transmitted PRACH but did not receive any response from the network, it increases its power in fixed step (or increases number of PRACH repetitions) and sends PRACH preamble again.

Msg2: eNodeB sends a Random Access Response to UE on Downlink Shared Channel (DL-SCH) addressed to RA-RNTI calculated from the timeslot in which preamble was sent. The message carries following information:

Temporary (cell radio network temporary identity) C-RNTI;

Timing Advance (TA) value: eNodeB also informs UE to change its timing so it can compensate for the round trip time caused by UE distance from the eNodeB;

Uplink Grant Resource: Network (eNodeB) will assign initial resource to UE so that it can use Uplink Shared Channel (UL-SCH). TA is the RTT correction value that the UE shall apply in its uplink transmission timing. This is because the uplink is synchronous among UEs, i.e. the eNodeB requires all UEs to time align their uplink transmission.

Msg3: Using UL-SCH, UE sends RRC connection request message to eNodeB.

Msg4: eNodeB responds with contention resolution message to UE whose message was successfully received.

[0051] After Msg4, the data communication could occur effectively. The UE can scan the Physical Downlink Control Channel (PDCCH) for any uplink or downlink DCI and transmit or receive data packets, respectively.

[0052] If the UE sends a coarse RTT metric in Msg1, the eNB can send Msg2 and Msg4 which include an indication of how many subframes later the UE needs to respond to these signals. The eNB can use the earliest indication of UE-reported RTT to modify scheduling. The eNB schedules responses to Msg2 and Msg 4, allowing a number of subframes suitable to allow the UE enough time to reply.

[0053] A UE located outside the configured cell radius (12, Fig. 1) requires a modified method of transmitting a preamble. This is because the preambles, and preamble formats, are only suitable for cells up to 107km. The UE can use the determination of distance/delay, calculated at block 101, Fig. 3, to determine a timing of a preamble. Details of a suitable method are described in European Patent Application 16306567.5. It is assumed that the UE can successfully transmit a detectable Msg1 and that the UE can successfully receive Msg2.

[0054] Upon detecting Msg2, the UE acquires the timing advance (TA) value from the eNodeB which corresponds to the fine tuning of its RTT estimate:

$$T_{RTT} = T_{RTT,init} + TA$$

where: $T_{RTT,init}$ is the initial RTT estimate that the UE used to successfully transmit Msg1;

T_{RTT} is the fine tuning of the RTT by utilizing the received TA value.

The UE can determine the RTT with a precision of $\pm 16 T_S$ which corresponds to the Msg2 TA value granularity, where T_S = 1/30720000 seconds.

Coarse round trip time metric

This metric is intended for the initial attachment of the UE and aims to indicate to the eNodeB a coarse estimate of the extended RTT. Since LTE operation is based on subframes of 1 ms duration, a convenient granularity for the coarse RTT metric is an integer number of subframes. This reduces the amount of data to signal the value. This metric can be called "*number of subframes*", n_{GP} and is derived by the following formula:

$$n_{GP} = \begin{cases} \left\lceil T_{RTT}(s) \big/ 1000(ms) \right\rceil, & T_{RTT} > T_{GP} \\ 0, & 0 \le T_{RTT} \le T_{GP} \end{cases}$$

where: T_{RTT} is the estimated round trip time at the UE, $0 \le n_{GP} \le N_{GP}$, and

$$N_{GP} = \left\lceil T_{RTT,\max}(s) \big/ 1000(ms) \right\rceil$$

where: $T_{RTT,\max}$ is the maximum round trip time that the cell extension feature shall support.

$T_{RTT,\max}$ and thus N_{GP} are predefined values known to both the UE and eNB. Figure 6 shows a table of values of n_{GP}, N_{GP} and the maximum coverage range. For example, with N_{GP} = 2 the possible values of n_{GP} are 0, 1, 2 and the maximum coverage range is 300 km.

Coarse round trip time indication during attachment

1. Coarse round trip time in Msg1

[0055] The metric n_{GP} can be indicated to the eNodeB as early as possible, i.e. in Msg1. During the RA procedure, the eNodeB tries to detect 64 possible preamble sequences. For indicating n_{GP}, additional preamble sequences can be defined which are grouped into preamble sequence sets of size *s,* each on corresponding to a specific n_{GP} value. The set size s can be a value of lower order of magnitude compared to 64, e.g. 4 or 8. An eNodeB which supports cell range extension can additionally scan for these sequences from which it can extract n_{GP}. Figure 7 shows example preamble sequences for a cell with a maximum range of 450km. The RTT can be 0, 1, 2 or 3 subframes in length. A set of preamble sequences {64,…,64+s} signal a RTT of 1 subframe in length. A set of preamble sequences {65+s,…,65+2s} signal a RTT of 2 subframes in length. A set of preamble sequences {66+2s,…,66+3s} signal a RTT of 3 subframes in length. In this example, N_{GP} = 3.

[0056] This method has the benefit of early indication of n_{GP}. However, it adds more complexity to the eNodeB side due to the extra scan of the additional preamble sequences and requires the UE to implement the new set of preamble sequences.

2. *Coarse round trip time in Msg3*

[0057] The UE can send n_{GP} in Msg3. or the RA procedure. Upon a successful Random Access Response (RAR) detection in subframe n, the UE transmits Msg3 in subframe $n+k_1$, where $k_1 \geq 6$.

[0058] A worst case scenario is that the UE has a time budget of 5 ms for a combination of RTT and Msg3 preparation. Typically, the UE has a time budget of 3 ms between an end of DL reception and a start of an UL transmission in order to allow DL packet reception and UL packet preparation. This leaves time for a RTT of 5 - 3 = 2ms. This corresponds to a maximum cover range of 300 km. Notice that upon the reception of Msg2 the UE no longer has to monitor the DL, hence it can utilize the full k_1 subframes for RTT + Msg2 reception + Msg3 preparation. Thus, for a RTT of 2 ms, the current LTE specifications do not need to be altered. This case is depicted in Figure 8.

[0059] If the maximum cell size is set to 450 km, then the maximum RTT is 3 ms. Given the worst case of k_1=6, this allows only 6- 3 = 3 ms of Msg2 reception and Msg3 preparation time. This case is depicted in Figure 9. This time budget may be a challenge for some UEs. In this case the eNodeB will not receive an Msg3 in subframe $n+ k_1$ and the RA procedure will repeat itself, resulting to uplink interference to other UEs. Then, there are two options:

(i) The UE shall choose the same PRACH subframe for Msg1 transmission and RA Preamble in order to result to the same RA-RNTI to resend Msg1. This is because the RA-RNTI is dependent on transmission subframe of a specific Preamble as specified in Section 5.1.4 of 3GPP TS 36.321. This way the eNodeB is indicated that possibly the same UE is retrying to attach. An eNodeB that supports the range extension feature could store RA-RNTIs which sent a successful Msg1 but never replied with Msg3 and make sure to schedule a returning RA-RNTI's Msg3 with a $k_1 \geq 7$. This option adds some complexity to the eNodeB scheduler but potentially accelerates the duration of the RA procedure completion.

(ii) The UE follows the normal RA procedure until the eNodeB selects $k_1 \geq 7$. This option does not require any additional complexity but potentially extends the duration of the RA procedure completion.

[0060] The n_{GP} value can reside within Msg3 and the *RRCConnectionRequest* (RRC-CR) message, specified in Section 6.2.2 of 3GPP TS 36.331, as shown in Figure 10. Note that in this example the maximum number of guard period subframes is N_{GP} = 2, hence the range of n_{GP} is {0, 1, 2}. The corresponding definition is:

RRCConnectionRequest field descriptions

numberOfGP-Subframes

Provides the experienced round trip time in multiples of subframes. eNB is expected to allow at least numberOfGP-Subframes subframes as guard period when scheduling uplink resources to that UE.

[0061] Figure 11 shows a typical RA flow when RTT = 2 ms where the relative timing between the eNodeB and UE uplink and downlink and other information are shown.

3. No coarse round trip time feedback during attachment

[0062] In this alternative, n_{GP} is not signaled during initial attachment. Instead, the UE waits until the initial attachment is finished and directly sends a fine RTT indication (as described above). To reach that point the UE may have to try to attach several times in case the eNodeB schedules any PUSCH transmissions (e.g. Msg3) in uplink subframes where the UE might not be able to meet the timings due to the increased RTT. The UE can try to re-attach several times before the fine RRT is indicated to the eNodeB.

4. Shorter coarse round trip time metric

[0063] Instead of signalling n_{GP}, the UE can indicate an even shorter message to the eNodeB to just notify the eNodeB that the UE is outside the regular cell radius. The UE can send a single-bit "range extension" flag and the eNB can assume the largest supported extended RTT (e.g. n_{GP} = 2 or 3ms) during the initial stages of attachment until the UE can communicate a finer RTT estimate.

<u>Fine round trip time metric</u>

[0064] This metric indicates a finer RTT estimate to the eNodeB after the initial attachment of the UE. This metric may be signalled together with other parameters the UE indicates to the eNodeB after initial attachment. Since these messages are longer, a finer RTT is possible to be sent, i.e. with a finer granularity than 1ms. If G_{RTT} is the selected RTT granularity known to both the UE and eNodeB, then the finer round trip time metric $\tilde{T}_{RTT}$ is defined as:

$$\tilde{T}_{RTT} = \left\lceil T_{RTT} / G_{RTT} \right\rceil$$

[0065] A suitable granularity can be in the range of a few hundreds of µs, e.g. G_{RTT} = 100 µs.

[0066] This finer RTT estimate is sent to the eNodeB in order to provide a better RTT accuracy than 1ms. In LTE, the fine RRT value can be part of the measurement report the UE provides to the eNodeB. After $\tilde{T}_{RTT}$ is acquired at the eNodeB, it is regularly updated with the TA values the eNodeB estimates and indicates to the UE through DCIs. The eNodeB can now locally estimate how many subframes shall be used as guard period by deriving:

$$\tilde{n}_{GP} = \begin{cases} \left\lceil \tilde{T}_{RTT}(s) / 1000(ms) \right\rceil, & \tilde{T}_{RTT} > T_{GP} \\ 0, & 0 \le \tilde{T}_{RTT} \le T_{GP} \end{cases}$$

where T_{GP} is the length of the guard period in a preamble format for a non-extended cell. This equation defines a ceiling function for round trip times greater than T_{GP}. For example, a RTT of 1.2 ms is rounded up to 2 ms (= 2 subframes), a RTT of 2.2 ms is rounded up to 3 ms (= 3 subframes), and so on.

[0067] The $\tilde{n}_{GP}$ value is then signalled to the UE as a connection parameter after the initial attachment and prior to the data exchange between the two ends. For example, $\tilde{n}_{GP}$ can be a RRC configuration parameter.

[0068] The RTT is expected to change during the connection due to UE mobility (e.g. air-to-ground communication). When RTT results to a different $\tilde{n}_{GP}$ than the configured one, the eNodeB shall reconfigure $\tilde{n}_{GP}$ through dedicated signaling. This is sufficient because the change rate of $\tilde{n}_{GP}$ is very low (at least a few tens of minutes) and reconfiguring it is not very latency critical. For example, to increase or decrease $\tilde{n}_{GP}$ by one, the UE has to travel approximately 150 km. For an airplane traveling with a speed of 1200 km/h this requires 7.5 minutes.

[0069] $\tilde{n}_{GP}$ can be signalled with the information carried in the Downlink Control Information (DCI) for each of the scheduled uplink and/or downlink packets. This can avoid a need for dedicated signaling and reconfiguration need to be avoided.

[0070] Instead of $\tilde{n}_{GP}$, DCIs can alternatively indicate *k*, i.e. the delay in subframes between the DCI reception in subframe *n* and the DL or UL data packet reception or transmission in subframe *n+k*, respectively. In this case, the eNodeB has to take $\tilde{n}_{GP}$ into account when deriving *k*.

<u>Range extension as coverage enhancement parameter</u>

[0071] Range extension is possible only to UEs able to apply coverage enhancement. Those UEs shall indicate the support of range extension using a new coverage enhancement parameter, additional to those specified in Section 4.3.29 of 3GPP TS 36.306. For example, for the existing CE ModeA and ModeB UEs, the following fields can be introduced in Release 14:

rangeExtension-CE-ModeA-r14

This field defines whether the UE when operating in CE Mode A supports range extension. It is mandatory for UEs of this release if *ce-ModeA-r14* is supported.

rangeExtension-CE-ModeB-r14

This field defines whether the UE when operating in CE Mode B supports range extension. It is mandatory for UEs of this release if *ce-ModeB-r14* is supported.

<u>UL-SCH scheduling with cell range extension</u>

[0072] This section describes the necessary actions required regarding the uplink shared channel (UL-SCH) scheduling given a configured $\tilde{n}_{GP}$ value from the eNodeB. The eNodeB and UE need to take $\tilde{n}_{GP}$ into account. The eNodeB uses $\tilde{n}_{GP}$ when scheduling uplink grants (through UL-related DCIs). The UE uses $\tilde{n}_{GP}$ to determine when to transmit the corresponding UL-SCH.

<u>(i) UL-SCH scheduling in frame structure type 1 (FDD)</u>

[0073] Typically, for frame structure type 1, when the eNodeB has sent an uplink grant in subframe *n*, the UE needs to transmit the corresponding uplink packet in subframe *n*+4, according to Section 8.0 of 3GPP TS 36.213, allowing 4 subframes for DCI reception and UL-SCH preparation and transmission. For a cell range extension capable UE, the new UL-SCH transmission timing is $n+4+\tilde{n}_{GP}$, where $\tilde{n}_{GP}$ is the last configured number of guard period subframes. Operation is shown in Figure 12. At block 201 the UE stores a value of $\tilde{n}_{GP}$. At block 202 the UE receives a scheduling grant in subframe n. At block 203 the UE prepares data to send on the uplink. At block 204 the UE sends the data on the uplink during subframe $n+4+\tilde{n}_{GP}$. In relation to FDD, the term "number of guard period subframes $\tilde{n}_{GP}$" means a number of additional subframes to wait between receiving a scheduling grant on the DL and sending data on the UL.

(ii) UL-SCH scheduling in frame structure type 2 (TDD, HD-FDD)

[0074] Generally, for cell range extension capable UEs, Table 4.2-2 of 3GPP TS 36.211 can be replaced by Figure 13. The eNodeB is not allowed to schedule an uplink transmission in subframe *n* for a combination of UL/DL configuration and $\tilde{n}_{GP}$, if this subframe is not indicated as an uplink subframe (U) in Figure 13.

[0075] Typically, for frame structure type 2 (TDD), when the eNodeB has sent an uplink grant in subframe *n*, the UE needs to transmit it in subframe *n*+*k*, according to Section 8.0 of 3GPP TS 36.211, where *k* depends on the UL/DL configuration.

[0076] For a cell range extension capable UE, *k* values are defined for each UL/DL configuration and each $\tilde{n}_{GP}$, where $\tilde{n}_{GP}$ is the last configured number of guard period subframes. This is because the UE indicates which special subframes and potentially UL subframes are intended to be used as additional guard period. This is needed because the UE needs to monitor the DL and be able to meet the synchronous uplink transmissions. Thus, it requires additional round trip time indicated by $\tilde{n}_{GP}$.

[0077] There are five requirements to construct the tables which define the subframe *k* which uplink grants received in subframe *n* are required to be sent in subframe *n*+*k*, listed below:

1. The UL-SCH transmission occurs at least $\tilde{n}_{GP}$+4 subframes after the reception of the uplink grant.
2. The UL-SCH transmission cannot occur in a subframe used as guard period by the UE.
3. Uplink grants of the same UL/DL configuration cannot point to the same subframe for UL-SCH transmission.
4. The UL-SCH transmission cannot occur during special subframes; hence, an uplink grant cannot point to a special subframe.
5. Uplink grants shall point to the first available subframe for UL-SCH which does not violate the previous requirements.

[0078] Non range-extended UEs continue to use a special subframe between DL and UL. Range-extended UEs can use the special subframe as a guard subframe.

[0079] Figures 14-17 show tables which provide values of *k* for UL/DL configurations 0-6 and $\tilde{n}_{GP}$ = 0, 1, 2 and 3, respectively. In these tables, (D) indicates DL subframes, (S) indicates special subframes, (U) indicates UL subframes, (SG) indicates special subframes used as GP, and (ULG) indicate UL subframes used as GP. Note that some combinations of TDD UL/DL configuration and $\tilde{n}_{GP}$ do not allow even a single UL subframe, hence UL transmissions are not possible (indicated by an "X" in the tables). Thus, if a UE detects a cell and the combination of the UL/DL configuration and the estimated n_{GP} at the UE does not allow even a single UL subframe per frame according to Figures 16 or 17 then:

Alternative 1. The UE shall not attempt to attach to that cell.

Alternative 2. The UE shall attempt to attach to that cell and send n_{GP} (or an extended range indication). By receiving n_{GP}, the eNodeB is also made aware of the absence of useful uplink subframes and can either reject this UE or reconfigure its TDD UL/DL configuration to one that would allow the UE to send UL transmissions. This could be dependent on the service request of Msg3, e.g. if UE sends *EstablishmentCause ::= emergency*, the eNodeB shall switch to a UL/DL configuration which would allow the UE to send its emergency signal. For other services in Msg3 e.g. *EstablishmentCause ::= mo-Data* the eNodeB could decide to reject this UE through a *RRCConnectionReestablishmentReject*, see Section 6.2.2 of 3GPP TS 36.331. This eNodeB behavior can either be part of the LTE specifications or open to eNodeB implementation.

UE reporting with cell range extension

UE procedure for reporting CSI with cell range extension

1. Aperiodic CSI reporting using PUSCH with cell range extension

[0080] Aperiodic CSI reporting is performed in PUSCH. Hence, this type of reporting is unaffected by range extension.

2. Periodic CSI reporting using PUCCH with cell range extension

[0081] The eNodeB shall configure the periodicity of periodic CSI reporting according to the following alternatives:

(i) Using the available uplink subframes for PUCCH periodic reporting considering the last configured $\tilde{n}_{GP}$. In case of a new $\tilde{n}_{GP}$ value, the eNodeB will be required to perform re-configuration to adjust the periodic reporting to the new $\tilde{n}_{GP}$ value.

(ii) Using the available uplink subframes for PUCCH periodic reporting considering the highest possible $\tilde{n}_{GP}$ value. This will not require re-configuration when a new $\tilde{n}_{GP}$ value is calculated. This solution, however, limits the number of subframes for PUCCH reporting.

Alternatively, the UE can discard any periodic reporting that collides with a UL subframe used as guard period, given that only a subset of reporting subframes is affected, i.e. some reporting UL subframes still exist.

UE procedure for reporting HARQ-ACK with cell range extension

HARQ-ACK reporting in frame structure 1

[0082] Hybrid Automatic Repeat Request (HARQ) is a mechanism by which a UE acknowledges if it correctly received data on the downlink. Typically, for frame structure type 1, when the eNodeB has sent a DL DCI in subframe *n*-4, the UE needs to transmit the corresponding ACK/NACK value in subframe *n*, according to Section 7.3 of 3GPP TS 36.213, allowing 4 subframes for DCI reception and HARQ-ACK preparation and transmission.

[0083] For a cell range extension capable UE, a HARQ-ACK shall be transmitted in subframe *n* if the corresponding DL DCI has been received in subframe n-4- $\tilde{n}_{GP}$.

HARQ-ACK reporting in frame structure 2

[0084] Frame structure type 2 uses HARQ-ACK bundling, i.e. sending one representative ACK value for a bundle of downlink packets if all packets were successful, or sending an NACK if at least one packet of the bundle was unsuccessful. The bundle size for each uplink subframe and the DL packet numbering since its reception are shown in Figure 18. E.g. for TDD UL/DL configuration #1 and for subframe *n*=2 the bundle is a combination of two packets received 6 and 7 subframes earlier.

[0085] In the case of range extension, uplink subframes which are used as guard period cannot be used for HARQ-ACK indications. Thus, the bundling needs to be re-designed according to the configured $\tilde{n}_{GP}$ value. Figures 18-21 show the values for *k* for $\tilde{n}_{GP}$ = 0, 1, 2, 3, respectively, where *k* is the delay (in subframes) between the reception of a PDSCH packet and its HARQ-ACK transmission. *k* can point to either a DL or a special subframe. Indices *k* which belong to the same HARQ-ACK subframe form a HARQ-ACK bundle $K : \{k_0, k_1, k_{M-1},\}$, where *M* is the length of the bundle.

[0086] Figure 22 shows apparatus at a wireless base station (e.g. base station) and/or a UE which may be implemented as any form of a computing and/or electronic device, and in which embodiments of the system and methods described above may be implemented. Processing apparatus 300 comprises one or more processors 301 which may be microprocessors, controllers or any other suitable type of processors for executing instructions to control the operation of the device. The processor 301 is connected to other components of the device via one or more buses 306. Processor-executable instructions 303 may be provided using any computer-readable media, such as memory 302. The processor-executable instructions 303 can comprise instructions for implementing the functionality of the described methods. The memory 302 is of any suitable type such as read-only memory (ROM), random access memory (RAM), a storage device of any type such as a magnetic or optical storage device. Data 304 used by the processor may be stored in memory 302, or in additional memory. Data 304 comprises timing data as described. The processing apparatus 300 comprises a wireless transceiver 308.

[0087] The above examples are provided by way of example only. The disclosure of this application is not restricted by the specific combination of steps shown in the figures, and described herein, but includes any appropriate subsets or combinations of steps performed in any appropriate order. Sections of the method may be performed in parallel.

[0088] The term 'user equipment' (UE) is used herein to refer to any device with processing and telecommunication capability such that it can perform the methods and functions according to the examples of the present invention. Those skilled in the art will realize that such processing and telecommunication capabilities can be incorporated into many different devices and therefore the term 'user equipment' includes mobile telephones, personal digital assistants, PCs and many other devices.

[0089] Although the invention focuses on the architecture of LTE standards up to Release 13, the same concepts can be used in other or future communication systems (e.g. 3GPP New Radio – NR).

[0090] Any range or device value given herein may be extended or altered without losing the effect sought, as will be apparent to the skilled person.

[0091] The skilled person may adapt the examples for use in any telecommunication network, such as 2G, 3G, 4G, 5G or with any other telecommunication standard without losing the effect sought.

[0092] It will be understood that the benefits and advantages described above may relate to one example or may relate to several examples. The examples are not limited to those that solve any or all of the stated problems or those that have any or all of the stated benefits and advantages.

[0093] Any reference to 'an' item refers to one or more of those items. The term 'comprising' is used herein to mean including the method blocks or elements identified, but that such blocks or elements do not comprise an exclusive list and a method or apparatus may contain additional blocks or elements.

[0094] The steps of the methods described herein may be carried out in any suitable order, or simultaneously where appropriate. Additionally, individual blocks may be deleted from any of the methods without departing from the spirit and scope of the subject matter described herein. Aspects of any of the examples described above may be combined with aspects of any of the other examples described to form further examples without losing the effect sought.

[0095] It will be understood that the above description of a preferred examples is given by way of example only and that various modifications may be made by those skilled in the art. Although various examples have been described above with a certain degree of particularity, or with reference to one or more individual examples, those skilled in the art could make numerous alterations to the disclosed examples without departing from the scope of this invention.

CLAIMS

1. A method of supporting extended range communication between a wireless base station and a first wireless device comprising, at the wireless base station:

receiving information from the first wireless device, the information indicative of a distance or a time delay between the wireless base station and the first wireless device;

determining, based on the received information, if the first wireless device is located beyond a first range; and

if it is determined that the first wireless device is located beyond the first range:

determining a first guard period to be used to communicate with the first wireless device, wherein the first guard period is longer than a second guard period used to communicate with a wireless device within the first range; and

sending an indication of the first guard period to the first wireless device;

wherein the information received from the first wireless device comprises a first indication of round trip time at a coarse granularity and a second indication of round trip time at a finer granularity than the first indication.

2. A method according to claim 1 wherein determining a first guard period comprises determining an integer number of subframes for the first guard period.

3. A method according to claim 2 wherein the first guard period is selected from a plurality of different values, each value being an integer number of subframes.

4. A method according to any one of the preceding claims comprising:

communicating with the first wireless device using the first guard period; and

communicating with a second wireless device using the second guard period, wherein the second wireless device is located within the first range.

5. A method according to any one of the preceding claims wherein the information received from the first wireless device comprises an indication of a round trip time between the wireless base station and the wireless device.

6. A method according to claim 5 wherein the indication of round trip time is received on an uplink random access channel.

7. A method according to claim 5 or 6 wherein the indication of round trip time indicates the round trip time as an integer number of subframes.

8. A method according to any one of claims 5 to 7 wherein the indication of round trip time is signalled by a preamble sequence which is different to preamble sequences used when the wireless device is located within the first range.

9. A method according to claim 7 or 8 wherein the indication of round trip time is received in a connection request message on an uplink Physical Random Access Channel, PRACH.

10. A method according to any one of claims 1 to 4 wherein the information received from the first wireless device comprises a flag indicating that the first wireless device is located beyond the first range.

11. A method according to claim 1 wherein the second indication of round trip time is received after a timing advance has been sent to the wireless device.

12. A method according to any one of the preceding claims wherein determining a first guard period and sending an updated indication of the first guard period to the first wireless device are repeated during a connection with the first wireless device.

13. A method according to any one of the preceding claims wherein the first guard period is used for TDD or HD-FDD operation, the method comprising:

using the first guard period between downlink and uplink subframes.

14. A method according to any one of the preceding claims comprising:

sending a scheduling indication during downlink subframe n to schedule an uplink data transmission;

determining an expected uplink subframe to receive the data based on n and the first guard period.

15. A method according to any one of the preceding claims comprising:

sending downlink data during a downlink subframe n; and

determining an expected uplink subframe to receive a hybrid automatic repeat request acknowledgement, HARQ-ACK, based on n and the first guard period.

16. A method according to any one of the preceding claims wherein determining the first guard period comprises calculating:

$$\tilde{n}_{GP} = \begin{cases} \left\lceil \tilde{T}_{RTT}(s) \big/ 1000(ms) \right\rceil, & \tilde{T}_{RTT} > T_{GP} \\ 0, & 0 \le \tilde{T}_{RTT} \le T_{GP} \end{cases}$$

where: $\tilde{n}_{GP}$ is an integer number of guard period subframes;

T_{GP} is the length of the guard period in a preamble format for a non-extended cell;

$\tilde{T}_{RTT}$ is round trip delay received from the wireless device.

17. A method of supporting extended range communication between a wireless device and a wireless base station comprising, at the wireless device:

determining a measurement indicative of a distance between the wireless device and the wireless base station;

determining data indicative of the distance based on the measurement;

sending the data to the wireless base station;

receiving an indication of a guard period to be used when communicating with the wireless base station, wherein the guard period has a first value when the wireless device is located beyond a first range of the wireless base station, and the guard period has a second value when the wireless device is located within the first range of the wireless base station, wherein the second value is smaller than the first value;

wherein the information sent from the first wireless device comprises a first indication of round trip time at a coarse granularity and a second indication of round trip time at a finer granularity than the first indication.

18. A method according to claim 17 wherein the data comprises an indication of a round trip time between the wireless base station and the wireless device.

19. A method according to claim 18 wherein the indication of round trip time is sent on an uplink random access channel.

20. A method according to claim 18 or 19 wherein the indication of round trip time indicates the round trip time as an integer number of subframes.

21. A method according to claim 20 wherein there are preamble sequences corresponding to different integer numbers of subframes, and the method comprises selecting and using a preamble sequence for the round trip time.

22. A method according to claim 19 or 20 wherein the indication of round trip time is sent in a connection request message on an uplink Physical Random Access Channel, PRACH.

23. A method according to any one of claims 17 to 22 comprising:

determining, based on the data indicative of the distance, if the first wireless device is located beyond the first range; and

sending an identifier which indicates if the first wireless device is located beyond the first range.

24. A method according to claim 17 wherein the second indication of round trip time is calculated as:

$$\widetilde{T}_{RTT} = \left\lceil T_{RTT} / G_{RTT} \right\rceil$$

where: $\widetilde{T}_{RTT}$ = fine round trip time metric;

T_{RTT} = estimated round trip time;

G_{RTT} = a granularity known to the wireless base station and the wireless device.

25. A method according to claim 17 to 24 comprising:

receiving a timing advance from the wireless base station;

updating a round trip time; and

sending the second indication of round trip time based on the updated round trip time.

26. A method according to any one of claims 17 to 25 comprising receiving an updated indication of a guard period during a connection with the wireless base station.

27. A method according to any one of claims 17 to 26 wherein the indication of the guard period is an integer number of subframes.

28. A method according to claim 20 wherein the integer number of subframes is calculated by:

$$n_{GP} = \begin{cases} \left\lceil T_{RTT}(s) \big/ 1000(ms) \right\rceil, & T_{RTT} > T_{GP} \\ 0, & 0 \le T_{RTT} \le T_{GP} \end{cases}$$

where: n_{GP} is an integer number of subframes;

T_{GP} is the length of the guard period in a preamble format for a non-extended cell;

T_{RTT} is round trip delay received from the wireless device.

29. A method according to any one of claims 17 to 28 wherein the first guard period is used for TDD or HD-FDD operation, the method comprising:

using the first guard period between downlink and uplink subframes.

30. A method according to any one of claims 17 to 29 comprising:

receiving a scheduling indication during downlink subframe n to schedule an uplink data transmission;

determining an uplink subframe to send the data based on n and the guard period.

31. A method according to any one of claims 17 to 30 comprising:

receiving downlink data during a downlink subframe n; and

determining an uplink subframe to send a hybrid automatic repeat request acknowledgement, HARQ-ACK, based on n and the guard period.

32. A method according to any one of the preceding claims wherein the wireless device is a Machine Type Communication device.

33. A wireless base station configured to perform the method of any one of claims 1 to 16.

34. A wireless device configured to perform the method of any one of claims 17 to 32.

35. A computer program product comprising a machine-readable medium carrying instructions which, when executed by a processor, cause the processor to perform the method of any one of claims 1 to 32.