Chapter 8

Cellular Positioning

8.1 Positioning in GSM Networks

- Cell-Id in combination with timing advance
- Enhanced Observed Time Difference (E-OTD)
- Uplink Time Difference of Arrival (U-TDoA)
- Assisted GPS (A-GPS)

8.1.1 GSM Air Interface

8.1.1.1 Multiple Access and Modulation

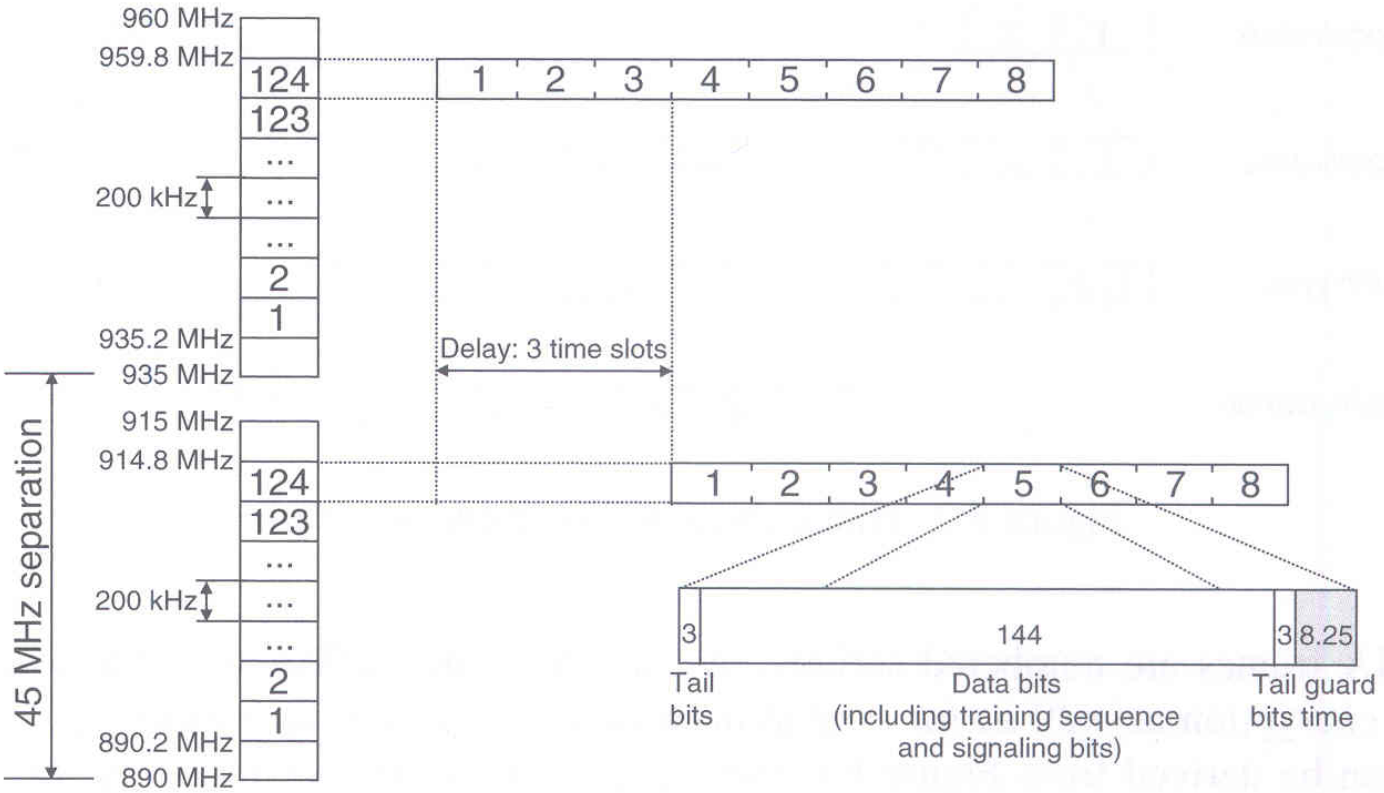

Figure 8.1 Organization of GSM air interface. Adapted from (Eberspächer et al. 2001).

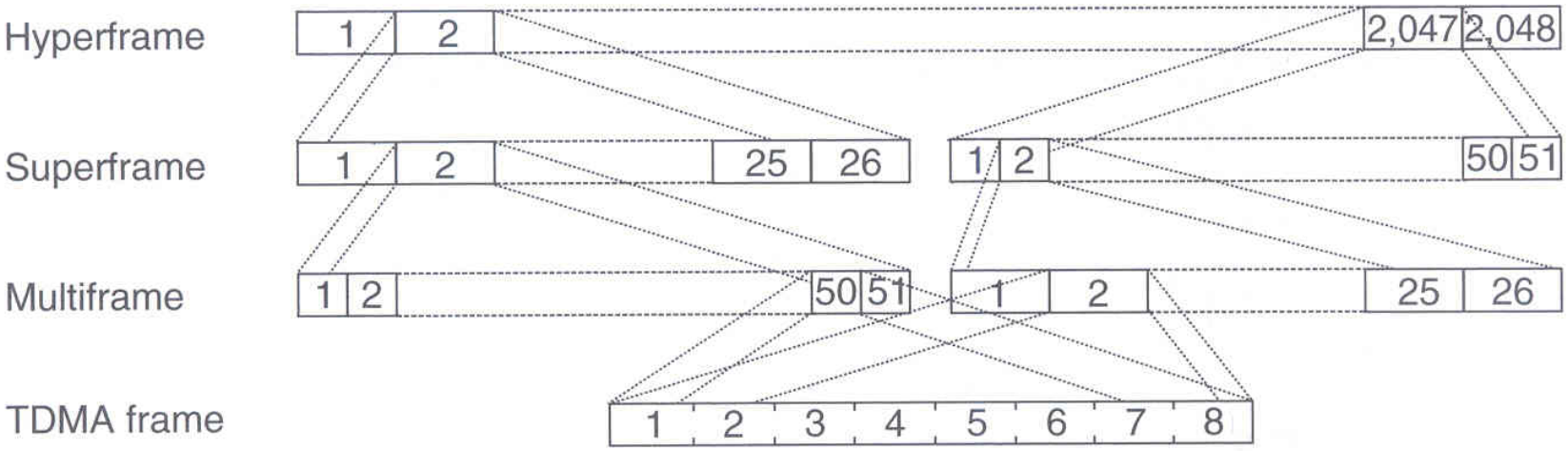

Figure 8.2 Hierarchical GSM frame structure.

8.1.1.2 Guard Times and Timing Advance

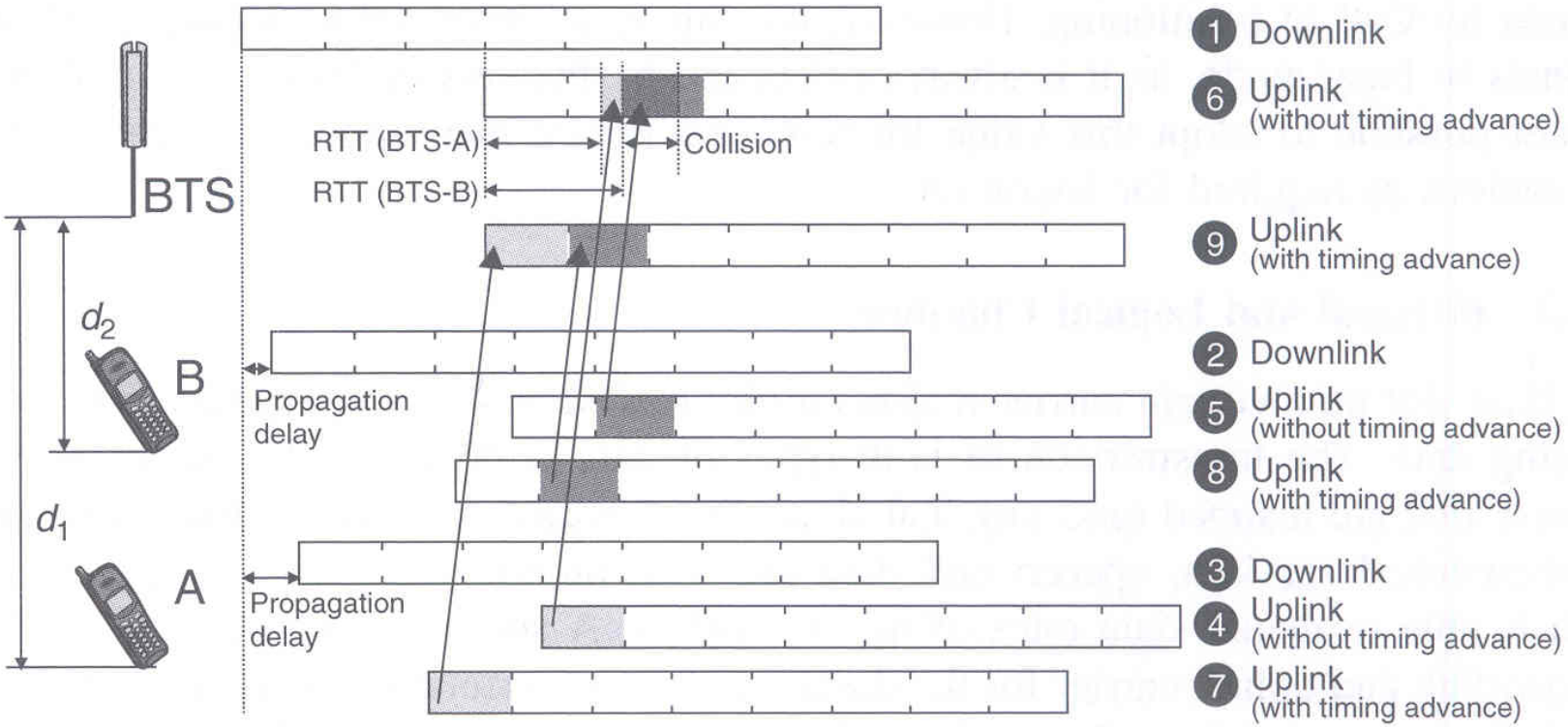

Figure 8.3 Propagation delay and timing advance.

8.1.1.3 Physical and Logical Channels

8.1.2 GSM Positioning Components

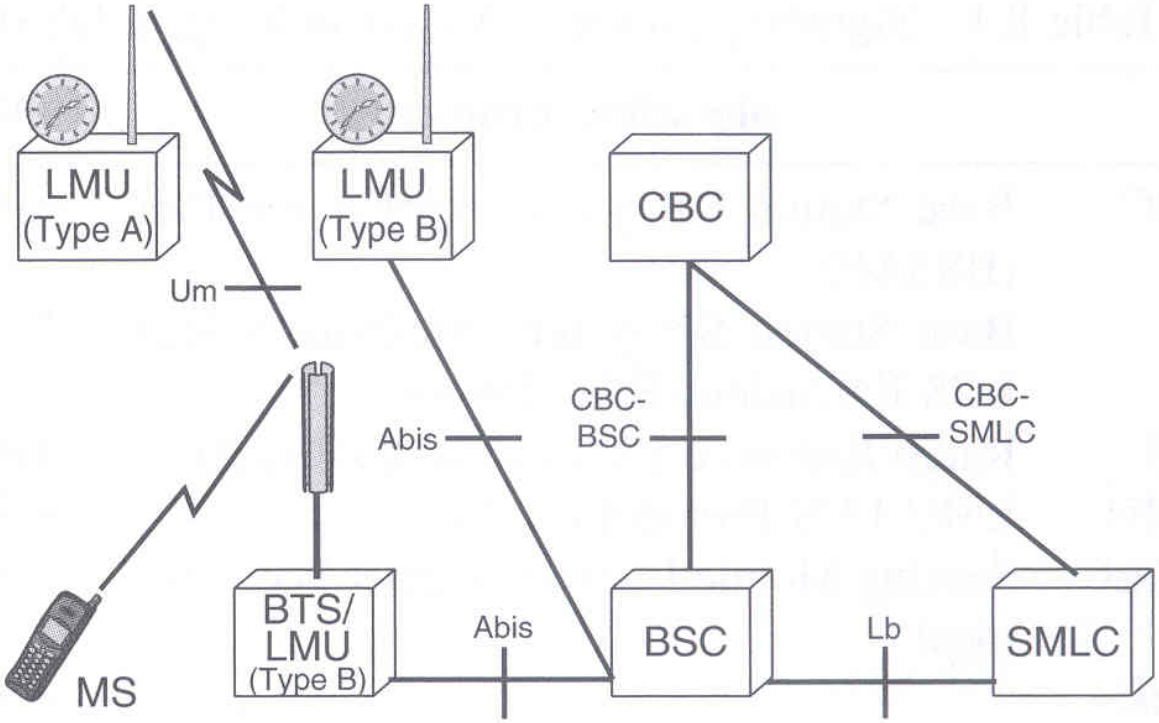

Figure 8.4 GSM positioning architecture.

Table 8.1 Signaling protocols for positioning in GSM

Components	**Signaling protocol**	**3GPP spec.**
SMLC ↔ BSC	Base Station Subsystem Application Part (BSSAP)	3GPP TS 48.008
	Base Station Subsystem Application Part LCS Extension (BSSAP-LE)	3GPP TS 49.031
SMLC ↔ MS	Radio Resource Link Protocol (RRLP)	3GPP TS 44.031
SMLC ↔ LMU	LMU LCS Protocol (LLP)	3GPP TS 44.071
SMLC ↔ SMLC	Serving Mobile Location Center Peer Protocol	3GPP TS 48.031
SMLC → CBC		3GPP TS 44.035
CBC → BSC		3GPP TS 23.041

8.1.3 Cell-Id Combined with Timing Advance

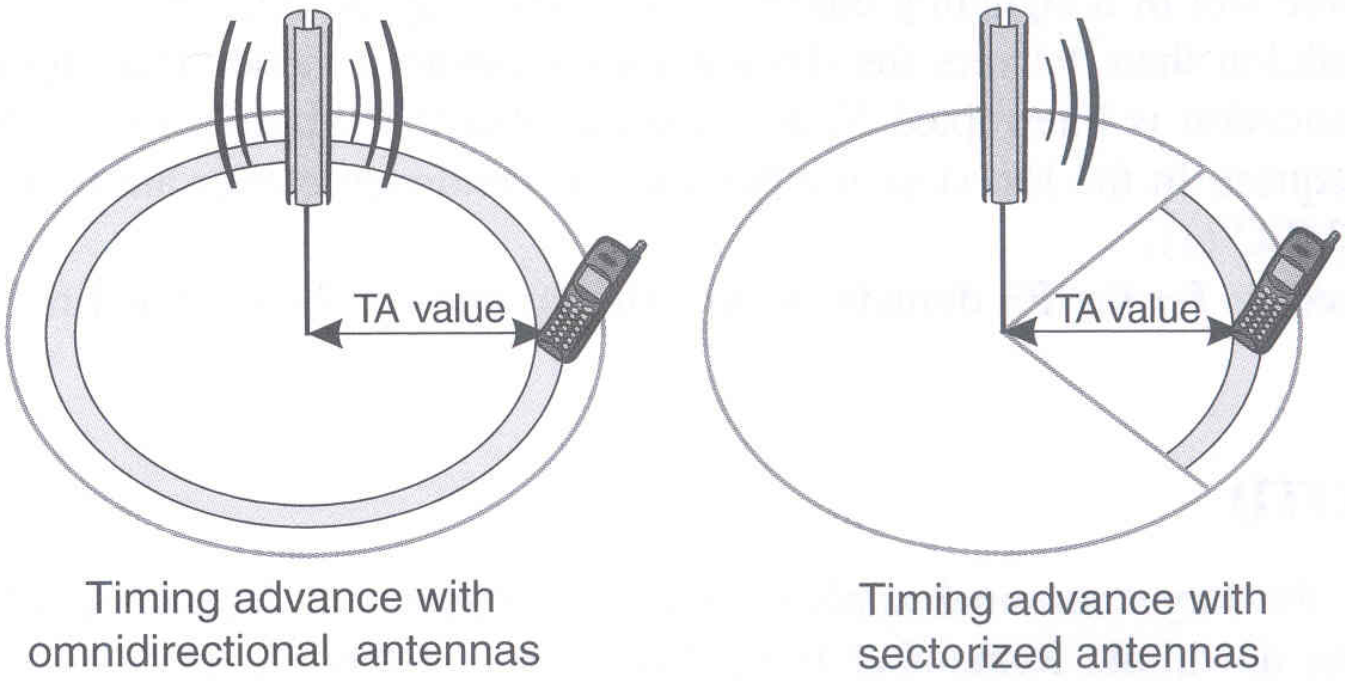

Figure 8.5 Timing advance with omnidirectional and sectorized antennas.

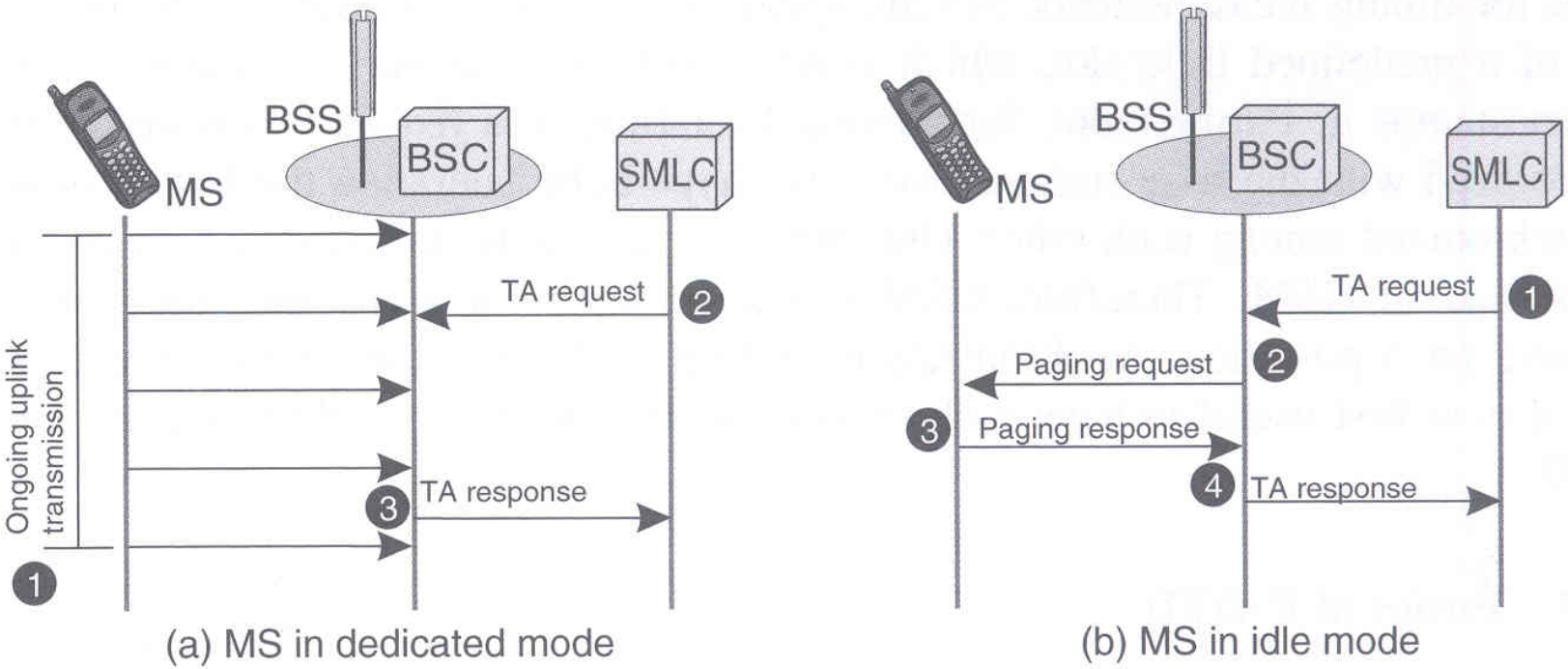

Figure 8.6 Control of TA in the circuit-switched domain.

8.1.4 E-OTD

8.1.4.1 Basics of E-OTD

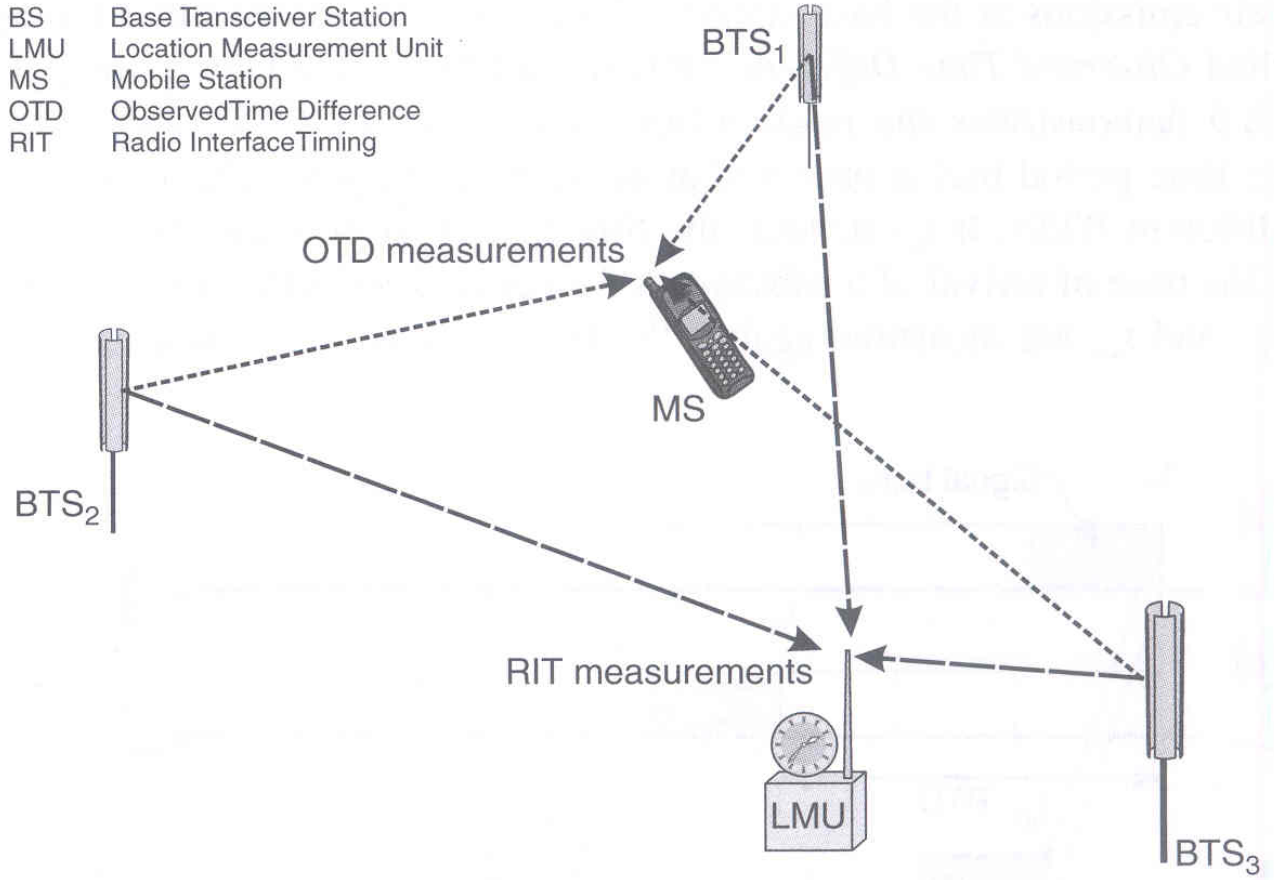

Figure 8.7 RIT and OTD measurements.

Hyperbolic E-OTD

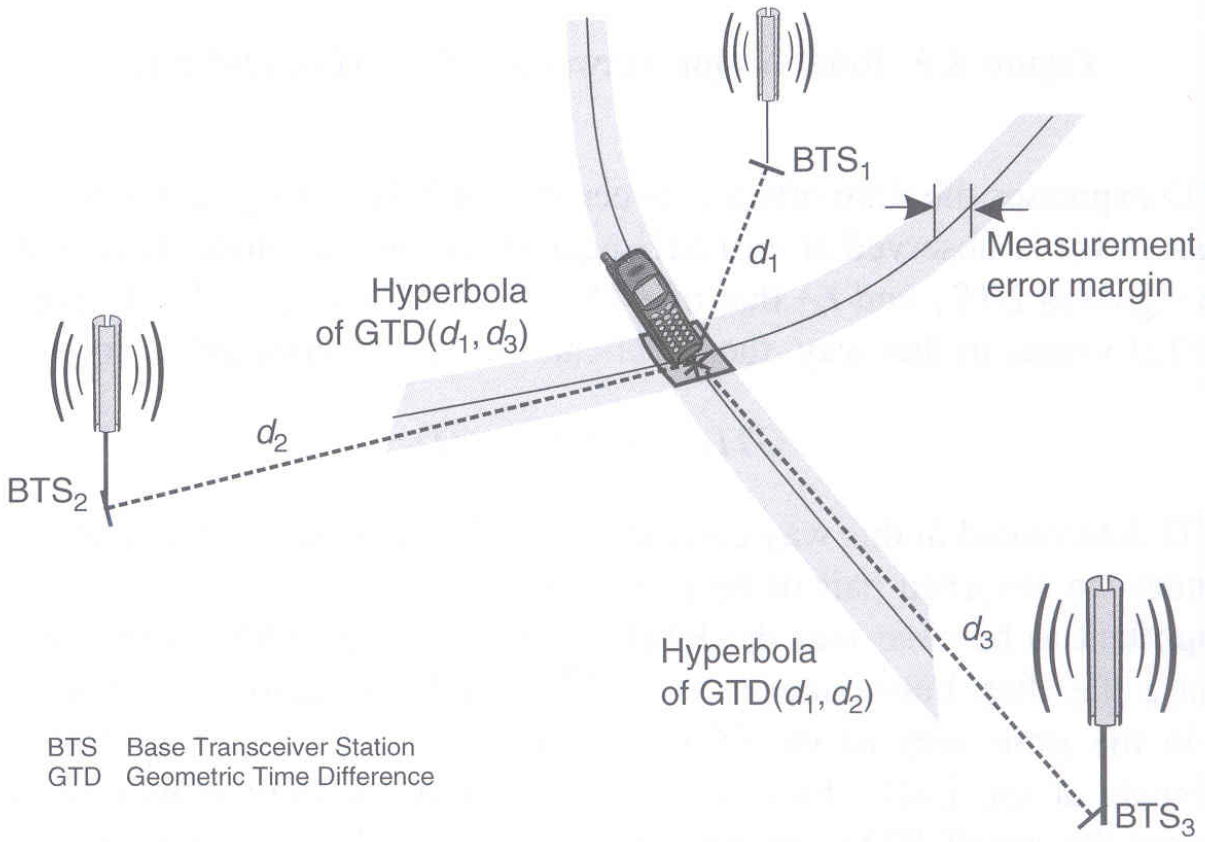

Figure 8.8 Hyperbolic D-TDoA.

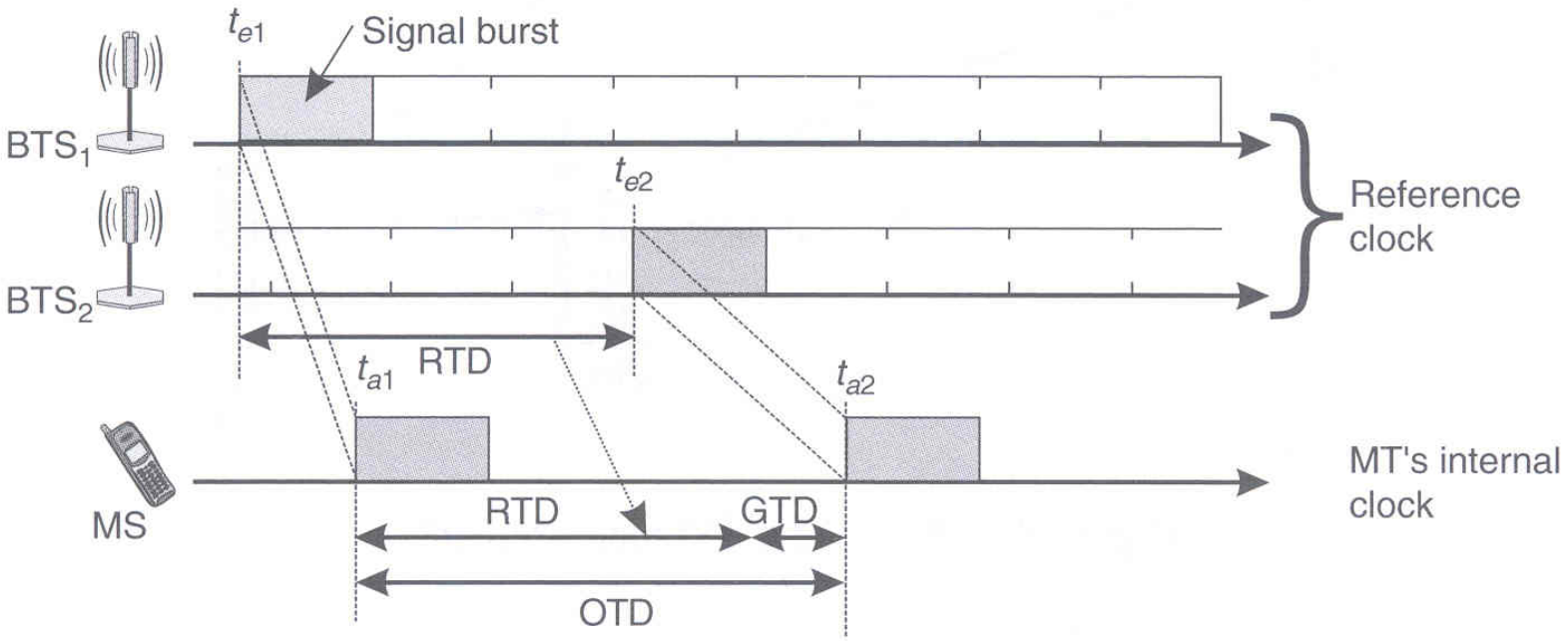

Figure 8.9 Relationship between GTD, OTD, and RTD.

$$GTD = OTD - RTD \tag{8.1}$$

Circular E-OTD

$$r_i - r_{i,LMU} = c(t_{i,MS} - t_{i,LMU} + \varepsilon) \tag{8.2}$$

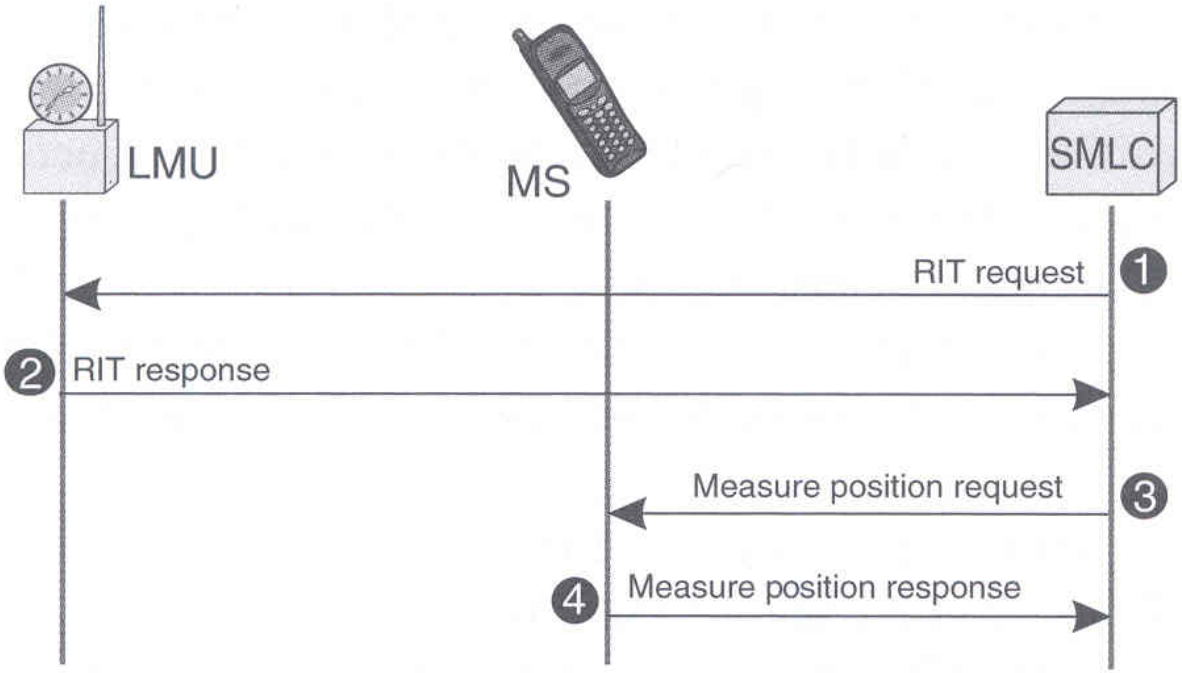

Figure 8.10 Coordination of measurements.

8.1.4.2 RIT Measurements

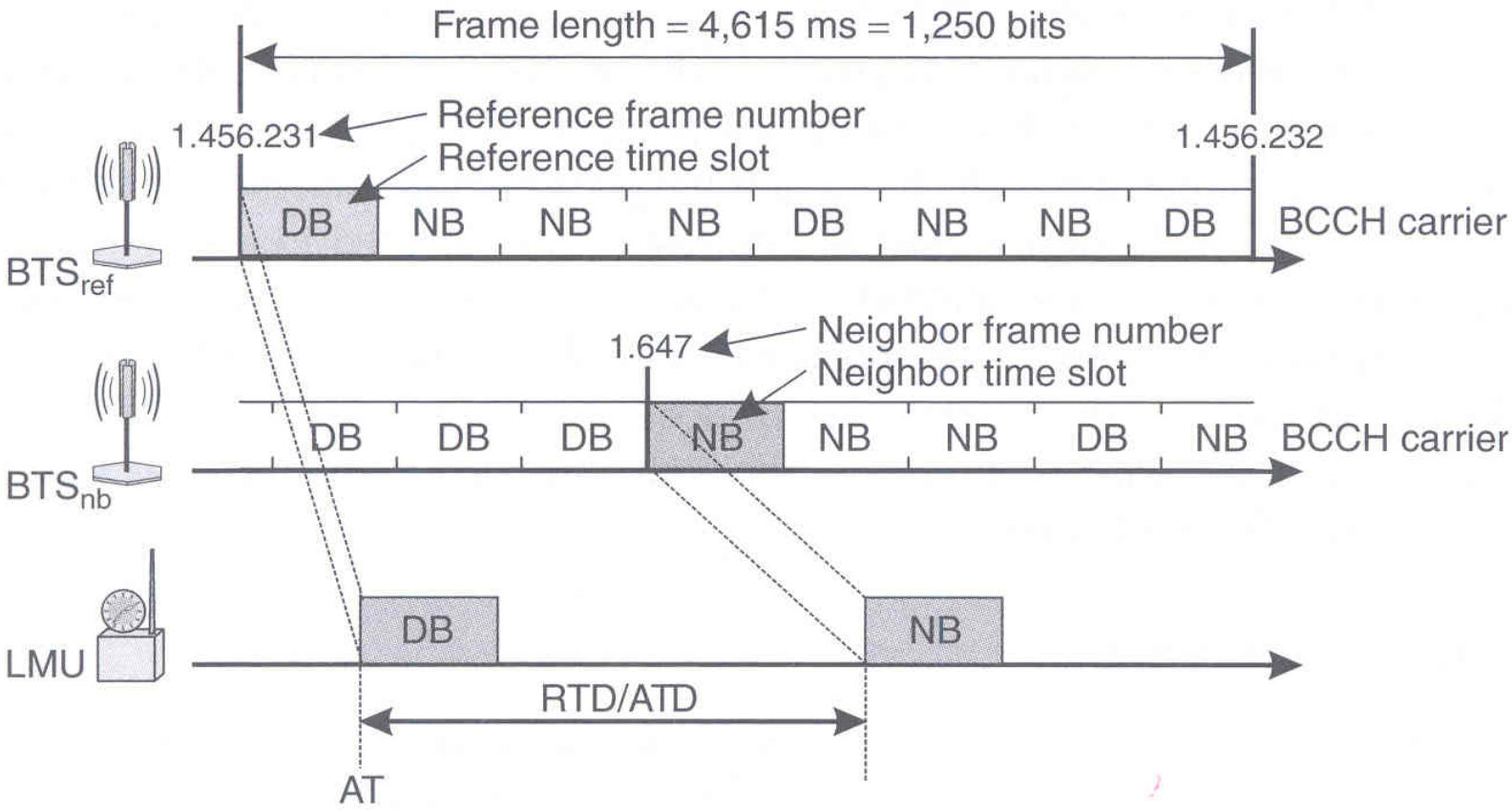

Figure 8.11 Determination of RTD.

- **Reporting of frame numbers**
- **Reporting of absolute time**

$$C_n = C_{n,n-1} + C_{n-1} \tag{8.3}$$

$$C_{n,n-1} = AT_n - AT_{n,\ \text{estimated}} \tag{8.4}$$

- **Reporting period**
- **Change limit**
- **Deviation limit**

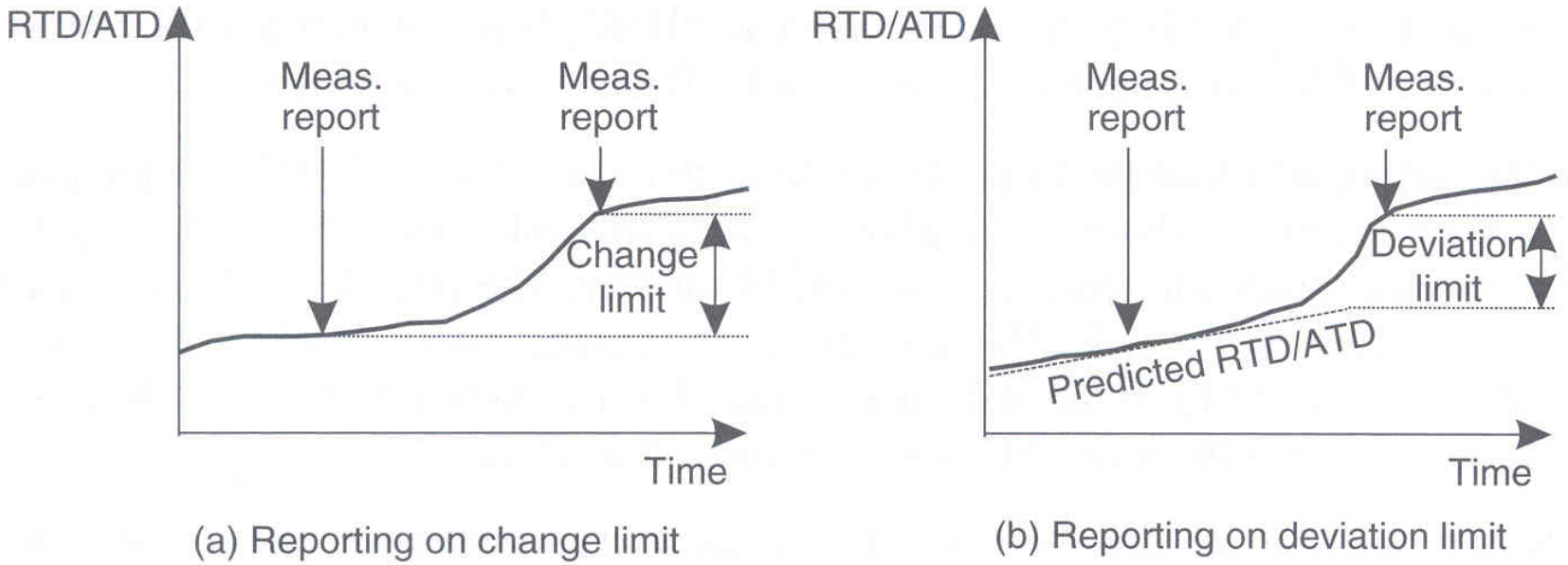

Figure 8.12 Reporting on change and deviation limit.

Table 8.2 Parameters of RIT measurement request in GSM (extract)

Parameters	Description
Measurement type	Indicates whether the SMLC wants the LMU to perform ATD or RTD measurements.
Reporting period	Instructs the LMU to send periodic reports with the frequency indicated by this parameter.
Change limit	Instructs the LMU to send extraordinary reports if AT or ATD/RTD values (with regard to the last reported values) has changed more than the limit specified by this parameter.
Deviation limit	Instructs the LMU to send extraordinary reports if the deviation of AT or ATD/RTD values exceeds the value specified by this parameter.
Environment characterization	Provides information about the expected multipath and line-of-sight conditions on the spot.
Reference and neighbor BTSs	Reference and neighbor cells to be monitored.

Table 8.3 Parameters of RIT measurement response in GSM (extract)

Parameter	Description
Reference BTS	Reference cell that has been used for measuring.
Reference frame number	Frame number of the last measured burst from the reference cell.
Reference time slot	Time slot of the last measured burst from the reference cell.
Response type	Indicates whether or not AT and ATD values of the reference BTS are reported.
Reference AT	GPS time of the last reference time slot.
Reference AT change	AT first time derivative of the AT value.
Reference RX level	Received signal strength of the reference cell.
Neighbor BTSs	Neighbor cells that have been used for measurements.
Neighbor frame number	Frame number of the last measured burst from the neighbor cell.
Neighbor time slot	Time slot of the last measured burst from the neighbor cell.
ATD/RTD value	Timing offset of reference and neighbor time slot.
ATD/RTD change	First time derivative of ATD/RTD since last measurement.

8.1.4.3 OTD Measurements

- Dedicated point-to-point signaling
- Broadcast signaling

- Terminal-assisted mode
- Terminal-based mode

- Mode of operation
- Reference and neighbor base stations
- Measurement support data
- Base station coordinates
- Response time and accuracy

Table 8.4 Parameters of OTD measurement request in GSM (extract)

Parameters	Description
Method type	Indicates whether terminal-assisted or terminal-based positioning is requested.
Response time	Specifies the desired response time.
Accuracy	Specifies the desired accuracy in case of terminal-based positioning.
Environment characterization	Indicates multipath and line-of-sight conditions on the spot.
Reference BTS	Specifies the reference cell to be monitored.
Reference BTS position	Coordinates of the reference BTS specified in latitude/longitude.
Neighbor BTSs	Neighbor cells to be monitored.
Multiframe offset	Difference in frames between the start of 51-multiframes of reference and neighbor cells.
Rough RTD	Beginning of reference and neighbor frames in terms of bits.
Fine RTD	Timing offset in 1/256 bit steps of reference and neighbor cell with regard to rough RTD.
Expected OTD	Rough estimation of the OTD based on the coordinates of the reference BTS, timing advance, and other data.
Relative north, east, and altitude	Relative position of neighbor BTS with respect to reference BTS.

Table 8.5 Parameters of OTD measurement response in GSM (extract)

Parameters	Description
Reference LAC and Cell-Id	Reference cell that has been used for measurements.
Reference time slot/Frame number	Time slot and frame number of the last measured burst from the reference cell.
Number of measurements	Indicates the number of measurements performed.
Number of measured neighbors	Number of different neighbor cells.
Neighbor LAC and Cell-Id	Neighbor cells that have been used for measurements.
Neighbor multiframe offset	Frame difference between the start of a 51-multiframe of the reference cell and each neighbor cell.
Neighbor time slots	Time slots of the last measured bursts of each neighbor cell.
OTD	Derived OTD for each pair of reference and neighbor cells.
Position estimation	Calculated terminal in latitude/longitude (in terminal-based mode only).

8.1.4.4 Overview of E-OTD Control Flow

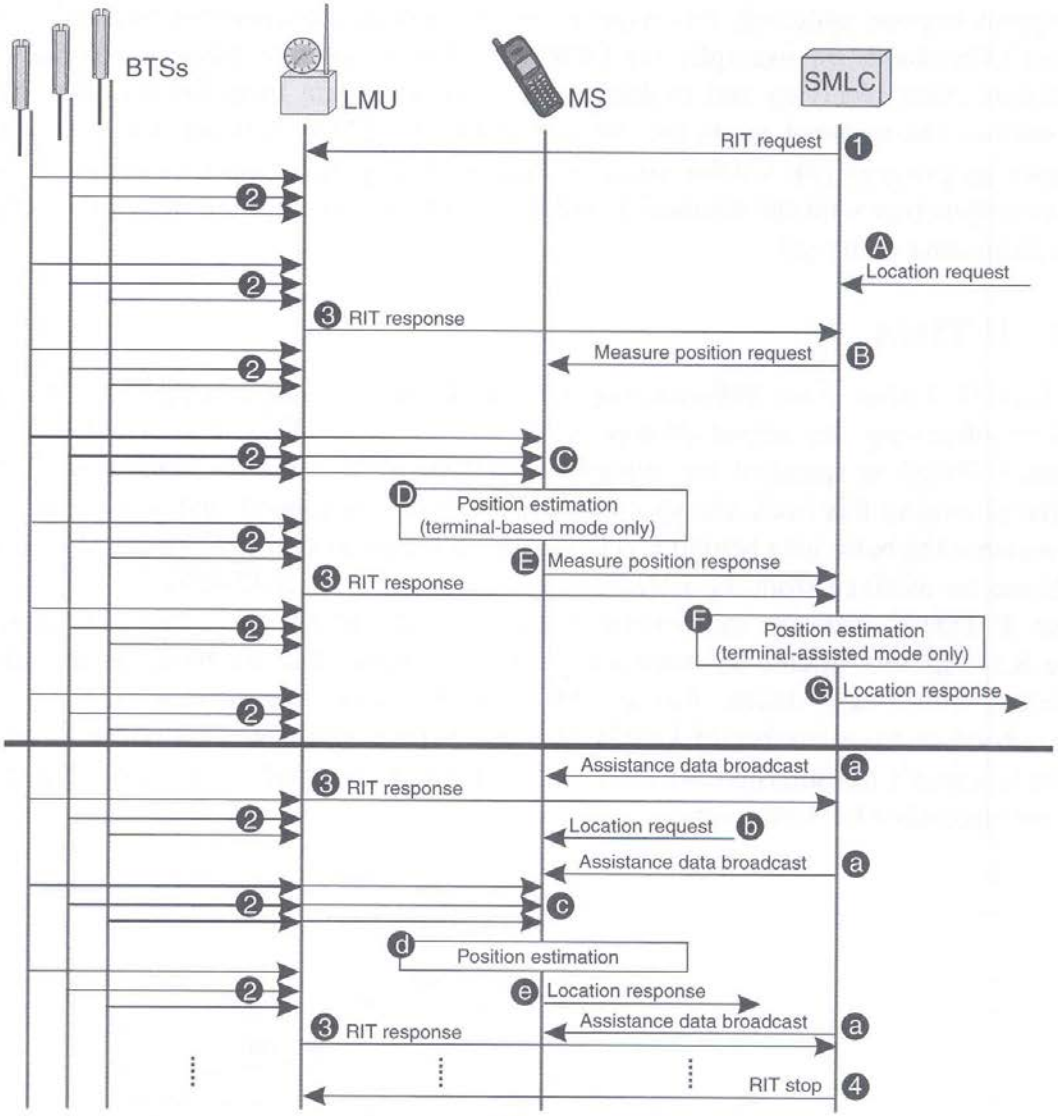

Figure 8.13 Overview of the E-OTD positioning process.

8.1.5 U-TDoA

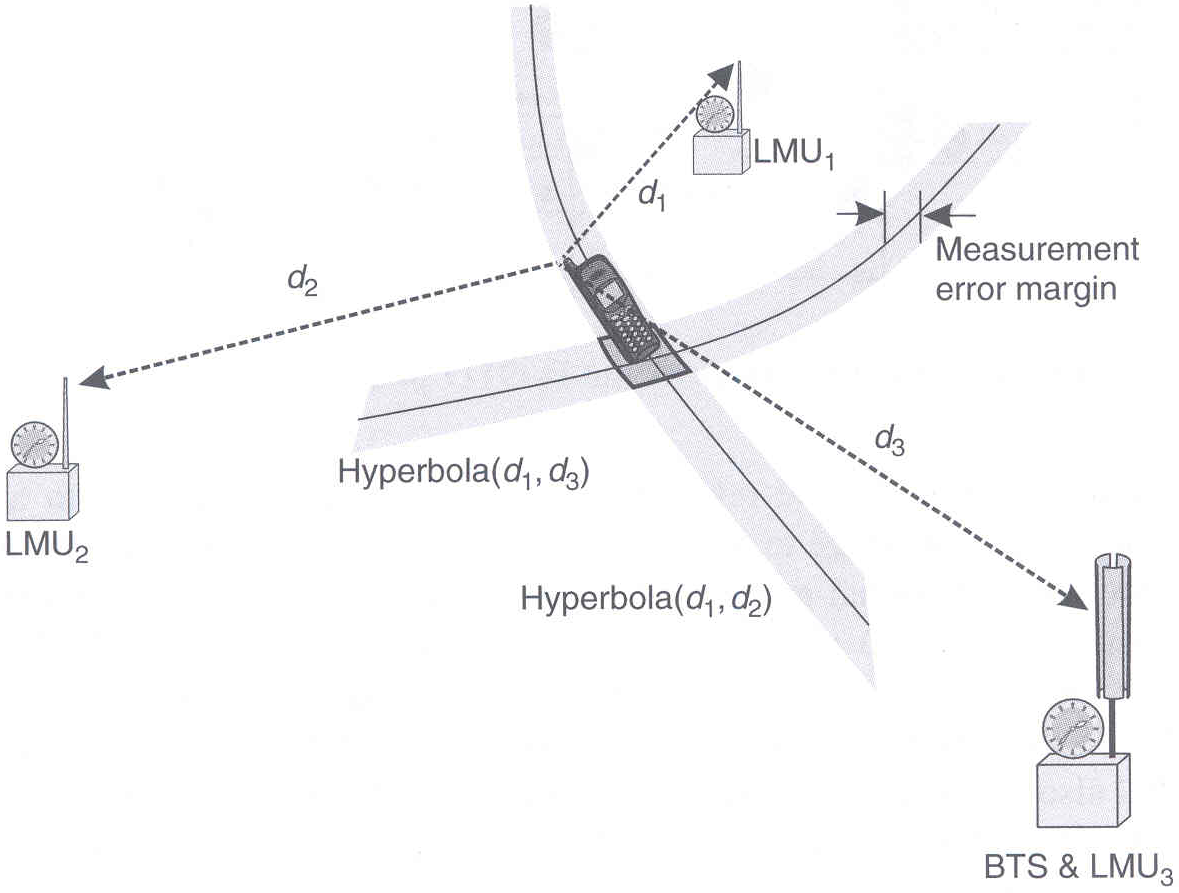

Figure 8.14 U-TDoA Configuration.

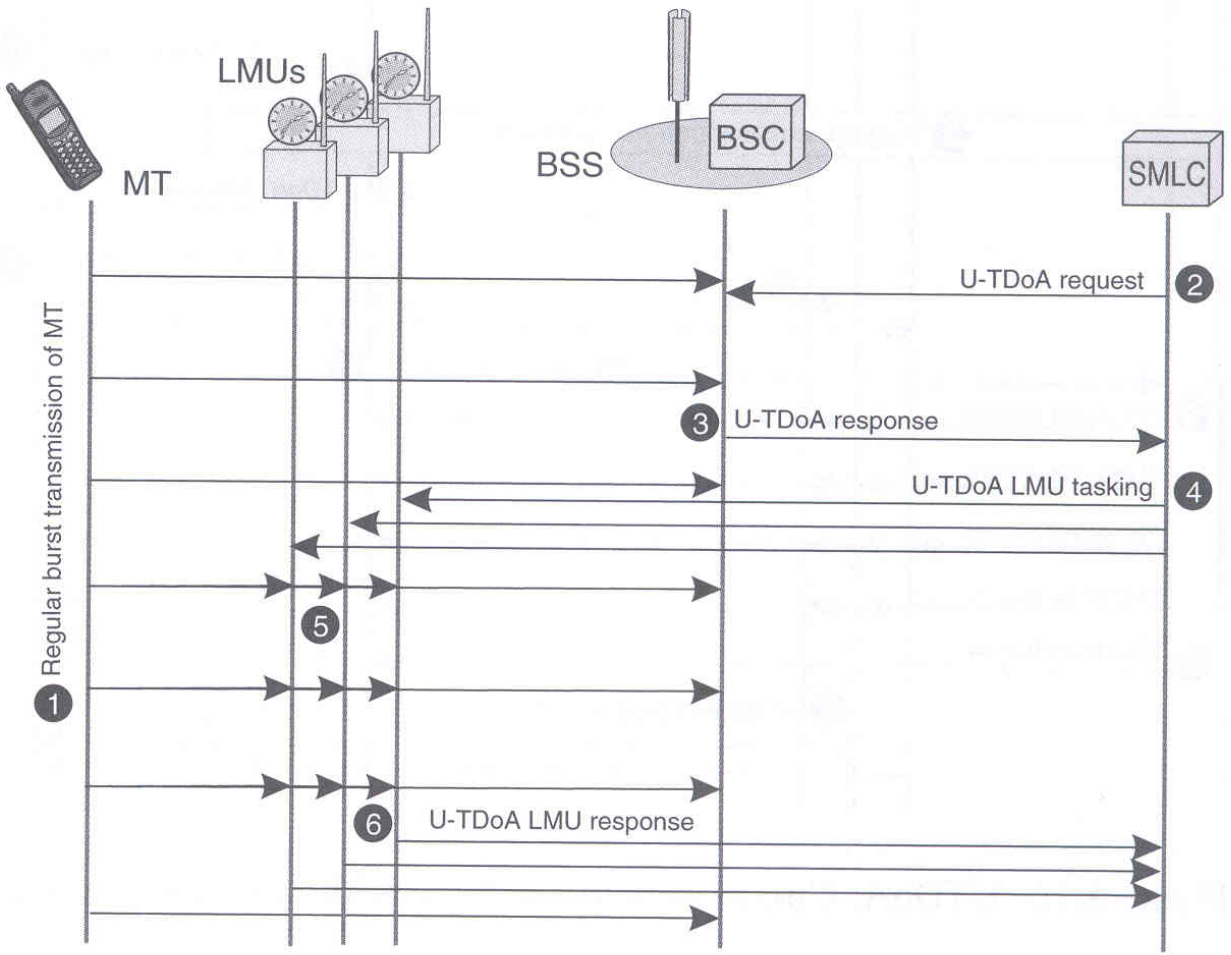

Figure 8.15 Overview of the U-TDoA positioning process.

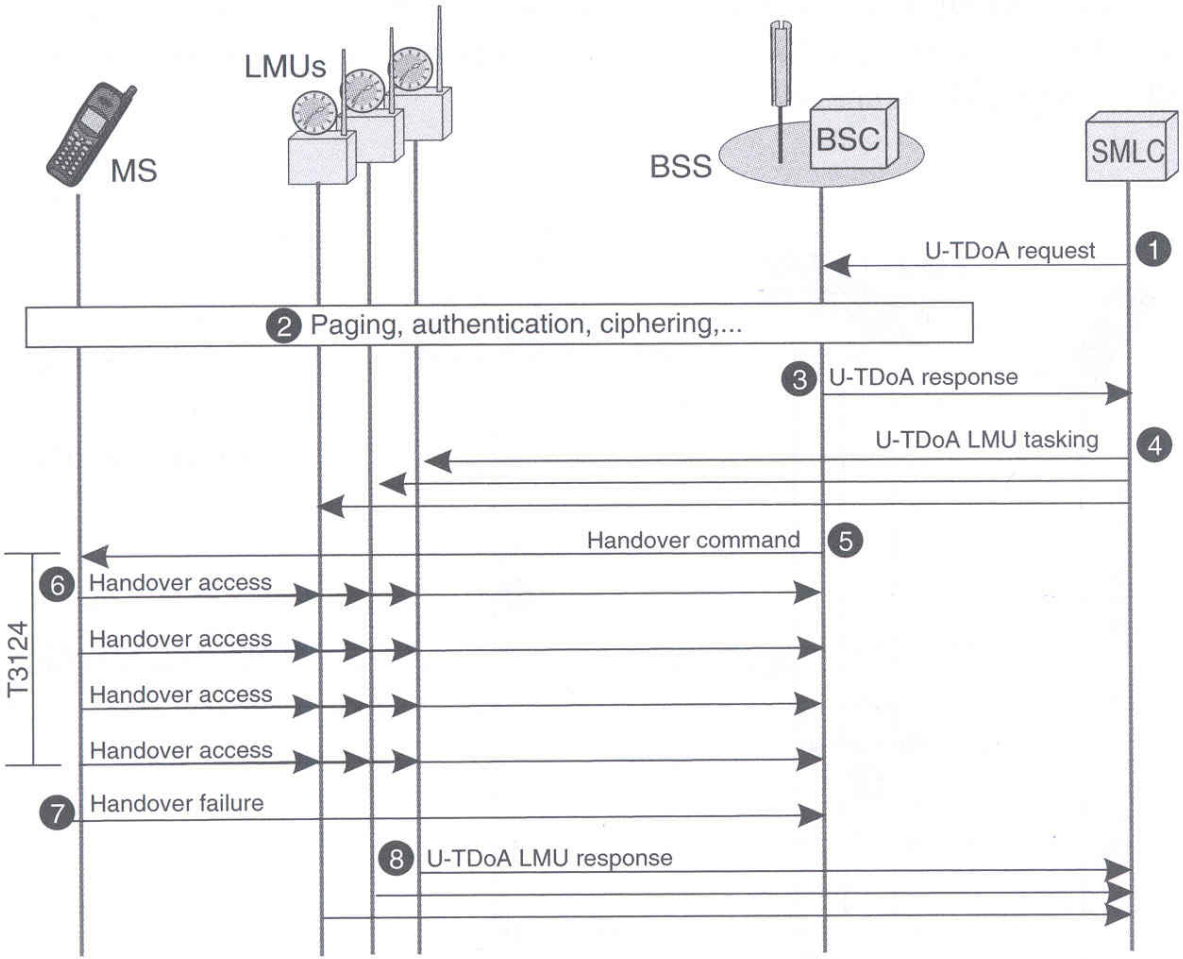

Figure 8.16 UTDoA: Circuit-switched domain with MT in idle mode.

8.2 Positioning in UMTS Networks

- Cell-based methods
- Observed time difference of arrival with idle period downlink (OTDoA-IPDL)
- Assisted GPS (A-GPS)

8.2.1 UMTS Air Interfaces

8.2.1.1 Multiple Access and Modulation

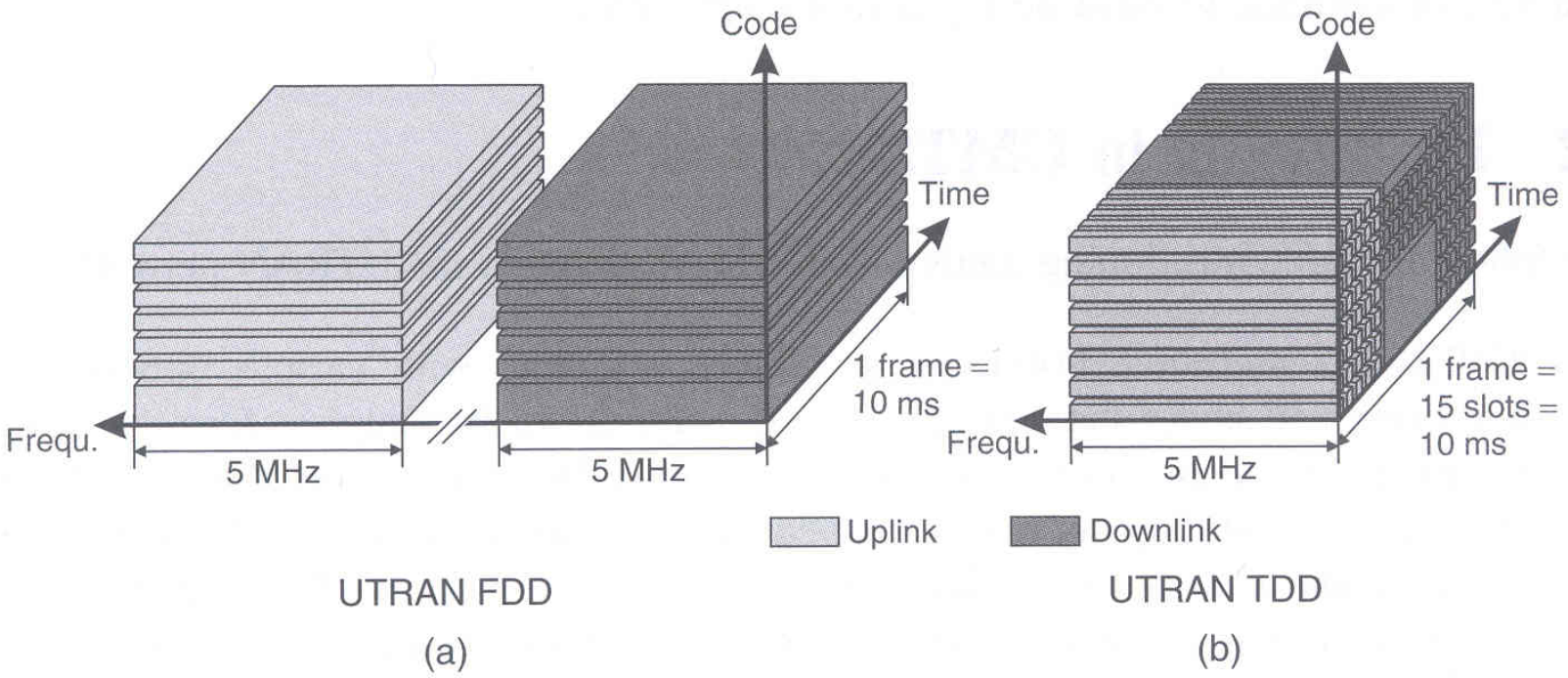

Figure 8.17 Organization of UMTS air interface.

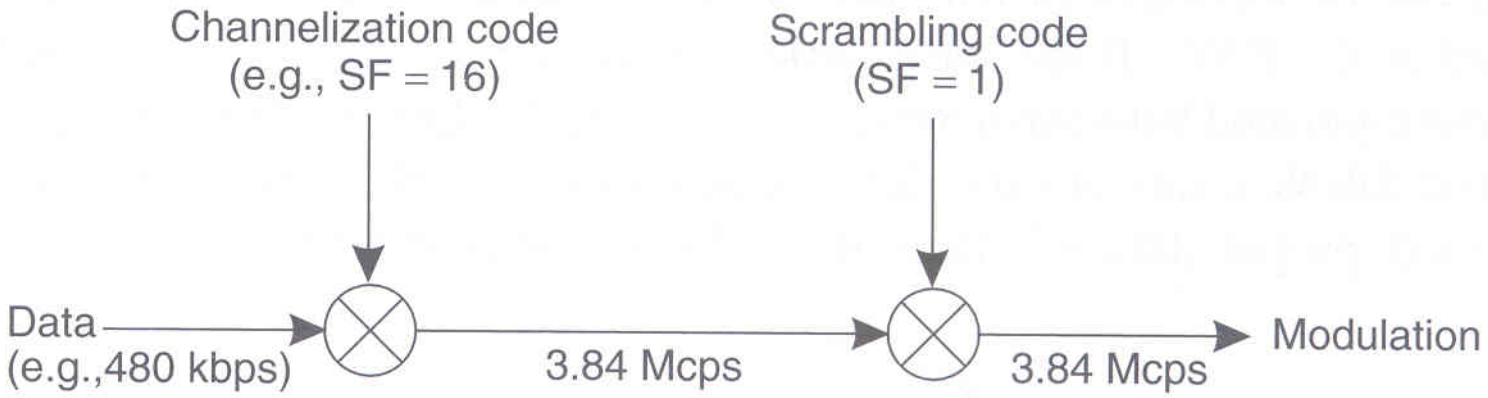

Figure 8.18 Encoding of data in UTRAN.

Table 8.6 UTRAN code types and their usage

	Uplink	**Downlink**
Scrambling codes	Subscriber separation	Cell separation
Channelization codes	Separation of channels from the same UE	Subscriber separation

8.2.1.2 Active Sets, Near–far Effect, and Hearability

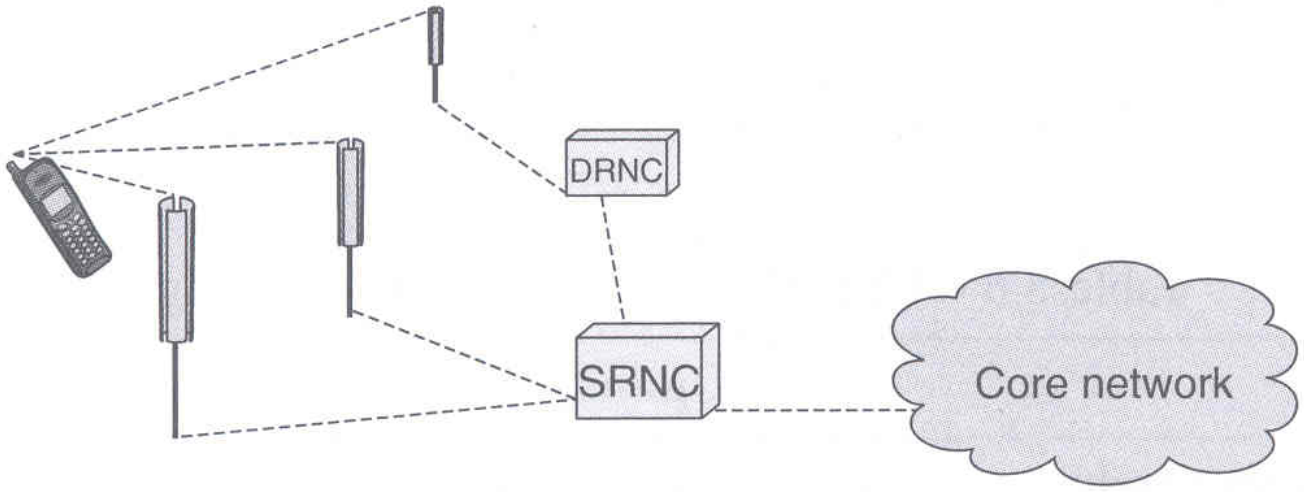

Figure 8.19 Signal branches between terminal and base station.

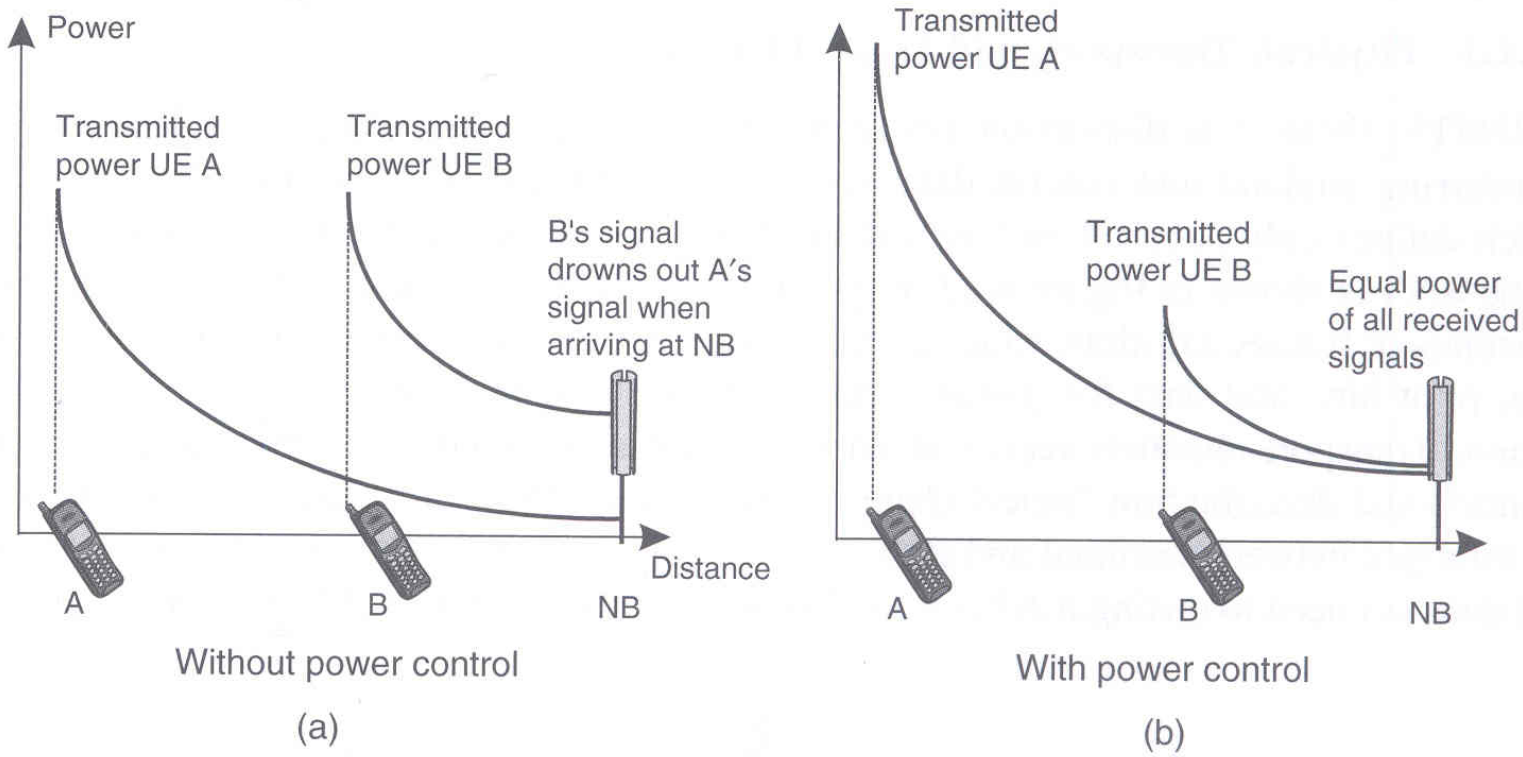

Figure 8.20 Near–far effect and power control.

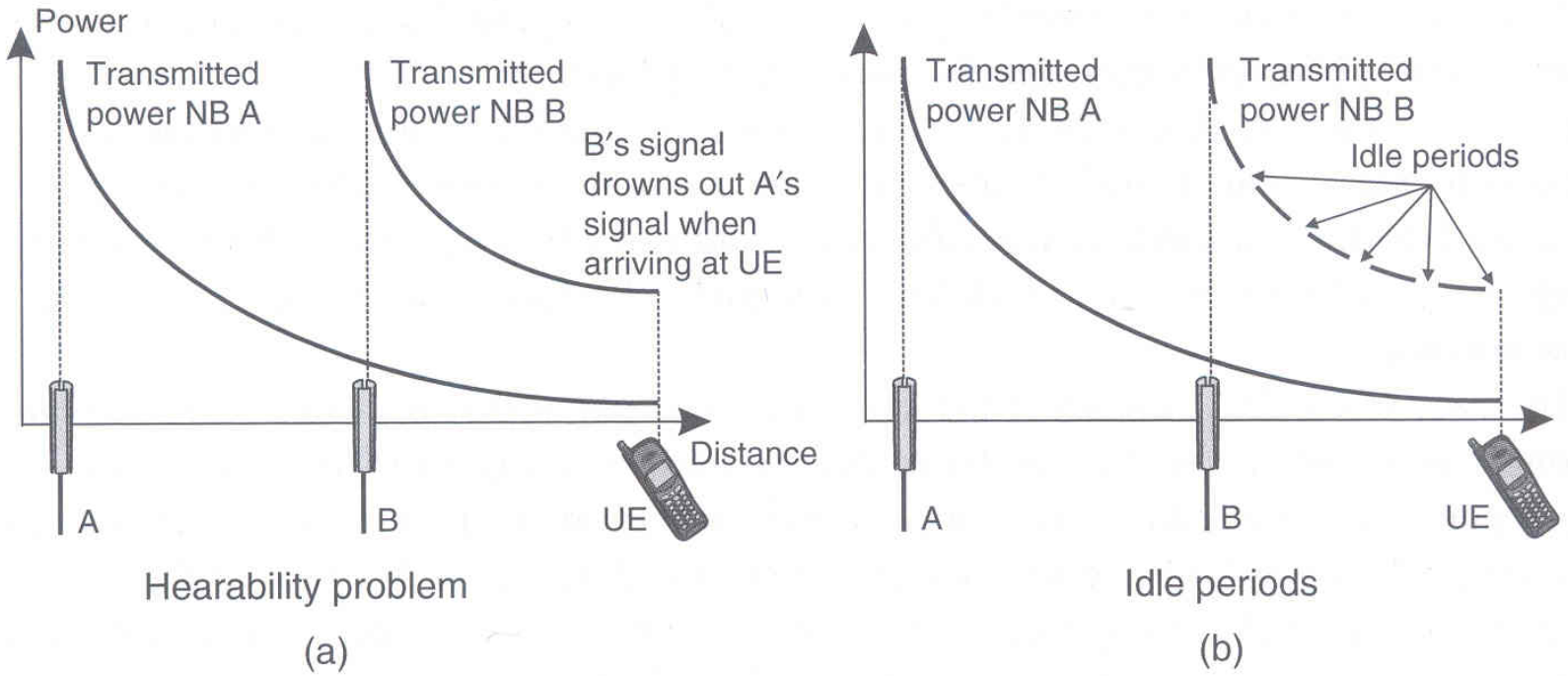

Figure 8.21 Hearability problem and idle periods.

8.2.1.3 Physical, Transport, and Logical Channels

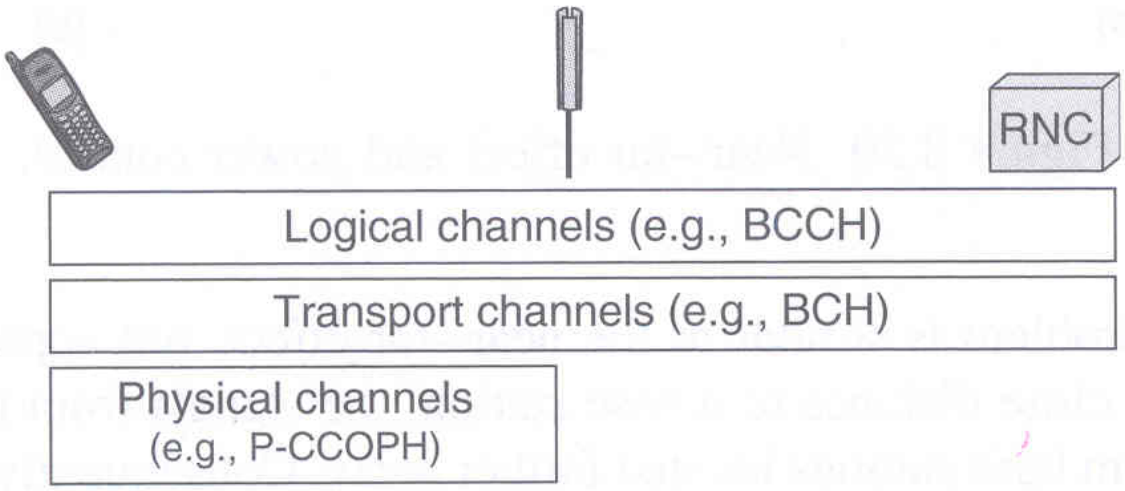

Figure 8.22 Arrangement of physical, transport, and logical channels.

8.2.2 UMTS Positioning Components

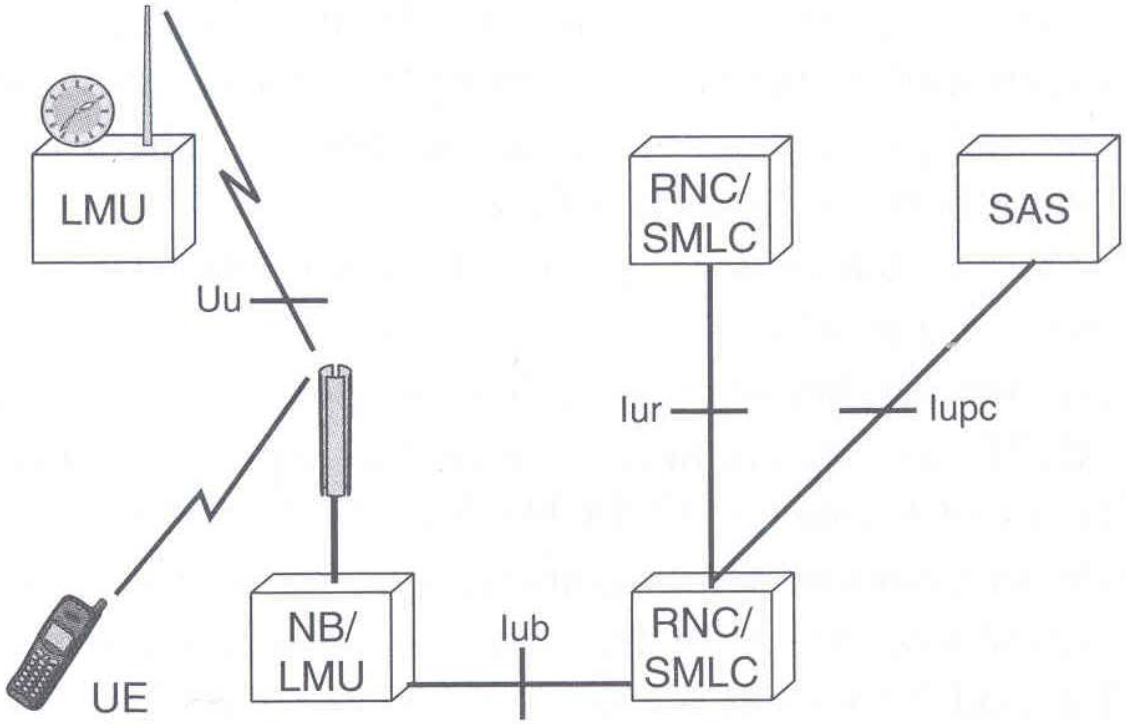

Figure 8.23 UMTS positioning architecture.

Table 8.7 Signaling protocols for positioning in UMTS

Components	**Signaling protocol**	**3GPP spec.**
RNC ↔ UE	Radio Resource Control (RRC) protocol	3GPP TS 25.331
RNC ↔ LMU(stand-alone)	Radio Resource Control (RRC) protocol	3GPP TS 25.331
RNC ↔ LMU(associated)	UTRAN Iub interface	3GPP TS 25.430
RNC ↔ SAS	UTRAN Iupc interface	3GPP TS 25.453
RNC ↔ RNC	UTRAN Iur interface	3GPP TS 25.423

8.2.3 Cell-based Methods

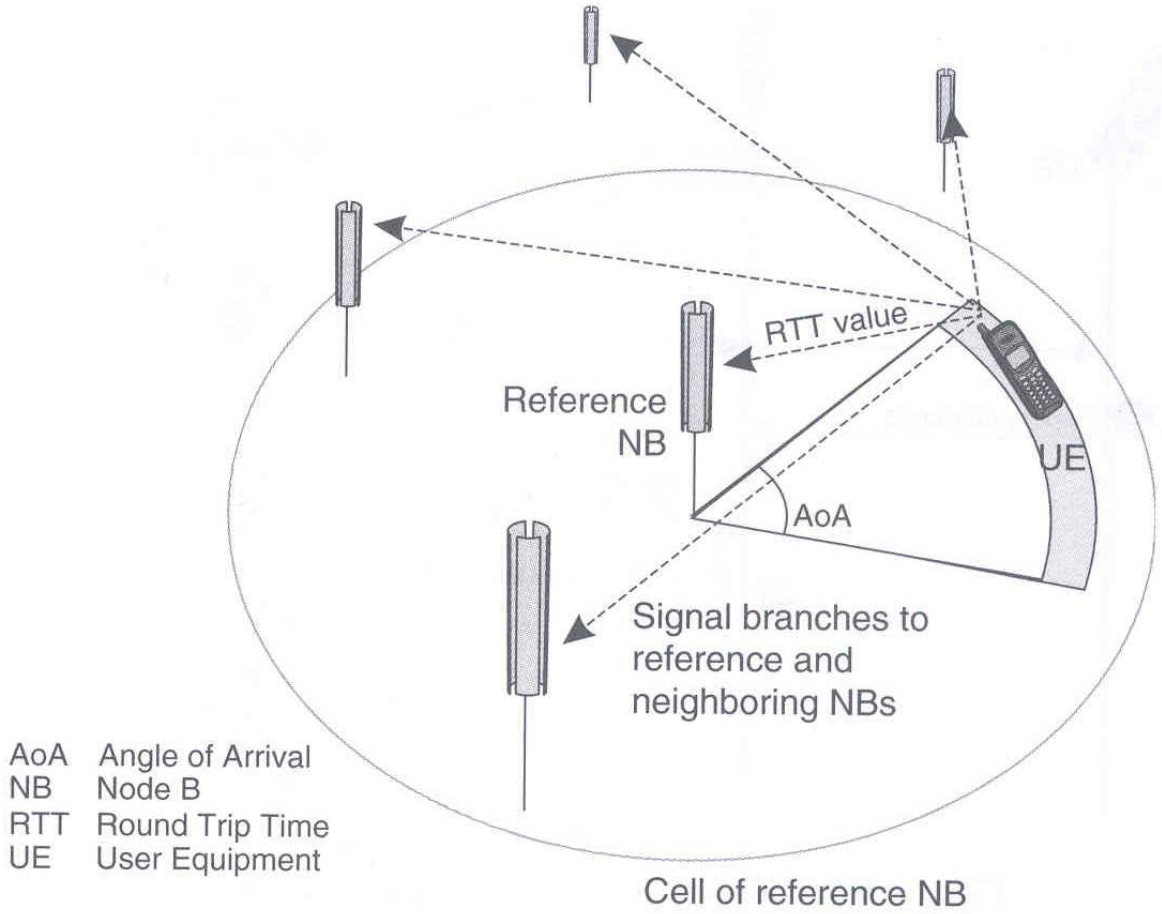

Figure 8.24 Cell-based positioning methods.

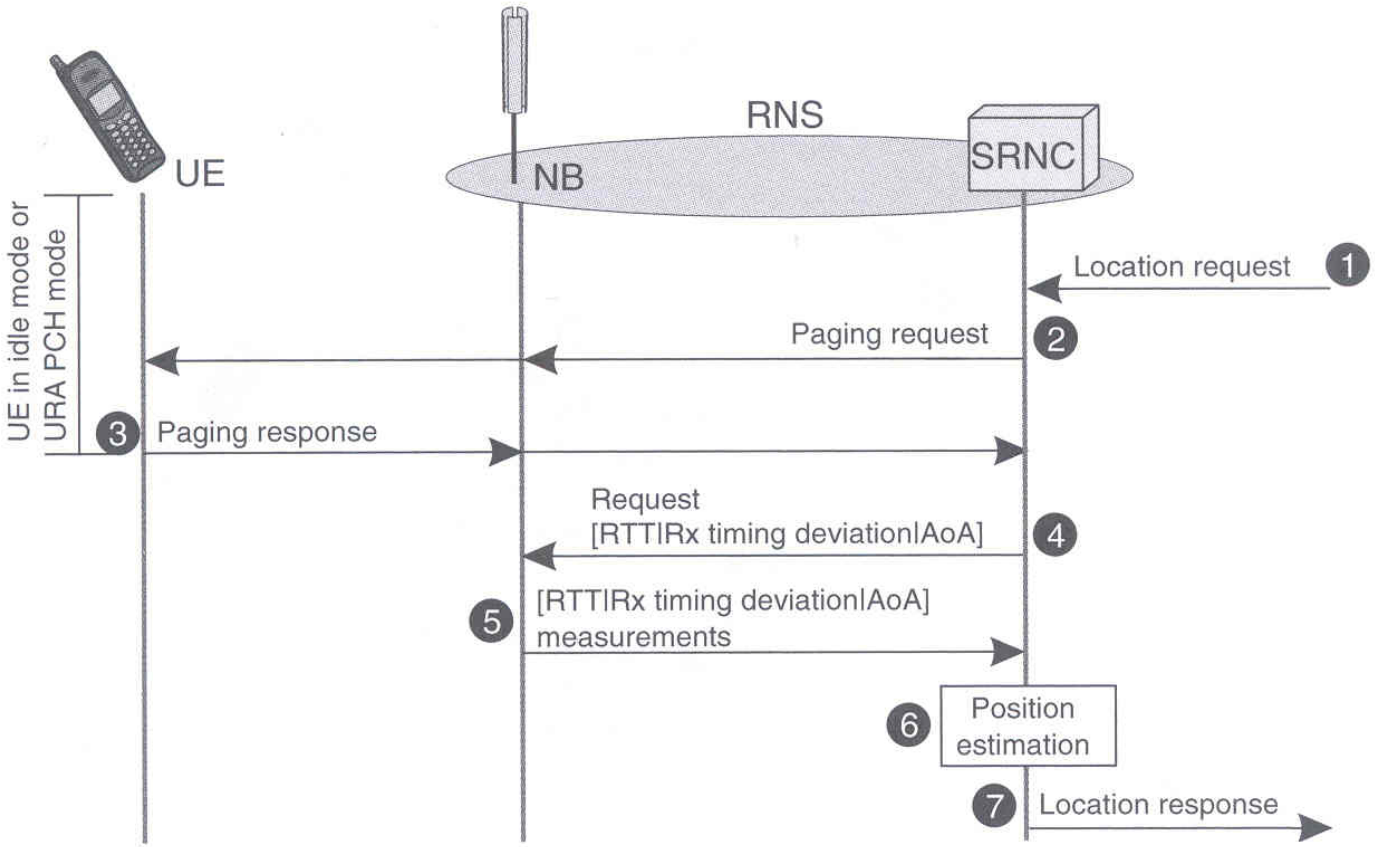

Figure 8.25 Control of cell-based positioning.

8.2.4 OTDoA-IPDL

8.2.5 RIT Measurements in UMTS

Table 8.8 Parameters of RIT measurement request in UMTS (extract)

Parameters	Description
Measurement type	Indicates whether the NB should measure the SFN–SFN observed time difference or UTRAN GPS timing of cell frames.
Report characteristics	Instructs the NB whether to return measurement reports on demand periodically or according to a change or deviation limit of either SFN–SFN observed time difference or UTRAN GPS timing of cell frames.
Environment characterization	Provides information about the expected multipath and line-of-sight conditions on the spot.
Neighbor cells	Defines the neighbor cells to be monitored.
Measurement accuracy	Defines the required accuracy by means of three classes if UTRAN GPS timing is activated.

Table 8.9 Parameters of RIT measurement response in UMTS (extract)

Parameter	Description
SFN	SFN of measured frame.
AT	GPS time of frame emission.
AT quality	Standard deviation of AT in 1/16 chip.
AT drift rate	Indicates the AT drift rate in 1/256 chip per second.
RTD	SFN–SFN observed time difference in chips.
RTD quality	Standard deviation of SFN–SFN observed time difference in 1/16 chip.
RTD drift rate	Indicates the drift rate of the SFN–SFN observed time difference in 1/256 chip per second.

8.2.5.1 OTD Measurements in UMTS

Table 8.10 Parameters of OTD measurement request in UMTS (extract)

Parameters	Description
Method type	Indicates whether terminal-assisted or terminal-based positioning is requested.
Response time	Specifies the desired response time.
Accuracy	Specifies the required accuracy of location estimation in case of terminal-based positioning.
Environment characterization	Expected multipath and line-of-sight conditions on the spot.
Reporting period	Instructs the UE to send periodic reports.
Change limit	Triggers extraordinary reports if OTD values have changed more than the limit specified by this parameter.
Position change	Triggers extraordinary reports if the current UE position has changed more than the value of this parameter.
Reference cell	Specifies the reference NB to be monitored.
Reference cell position	Coordinates in latitude/longitude of the reference NB.
IPDL	IPDL configuration of reference NB.
Neighbor cells	Specify the neighbor NBs to be monitored.
Neighbor cell position	Relative position of neighbor NB with respect to reference NB.
SFN offset	Difference in frames relative to the SFNs between the beginning of frames from the reference and a neighbor NB.
SFN–SFN relative time difference	Difference in chips between the beginning frames from reference and neighbor NBs in chips.
SFN drift	Indicates the clock drift of a reference NB in 1/256 chips per second.

Table 8.11 Parameters of OTD measurement response in UMTS (extract)

Parameters	Description
Reference cell	Specifies the measured reference NB.
Reference Rx–Tx time difference	Time difference between the UE uplink frame transmission and the first detected path of a downlink frame from the reference NB.
SFN	SFN of the frame from the reference NB that has been last measured.
Number of measurements	Indicates the number of measurements performed at the UE.
Neighbor cells	Specify the measured neighbor NBs.
Neighbor Rx–Tx time difference	Time difference between the UE uplink frame transmission and the first detected path of a downlink frame from a neighbor NB.
Measurement quality	Denotes the standard deviation of measured SFN–SFN OTD values and of Rx–Tx time difference that has been observed during the measurement period.
SFN–SFN OTD	OTD between the reference and a neighbor cell.
Position estimation	Calculated position in latitude/longitude of the UE if in terminal-based mode.

- **Continuous mode**
- **Burst mode**

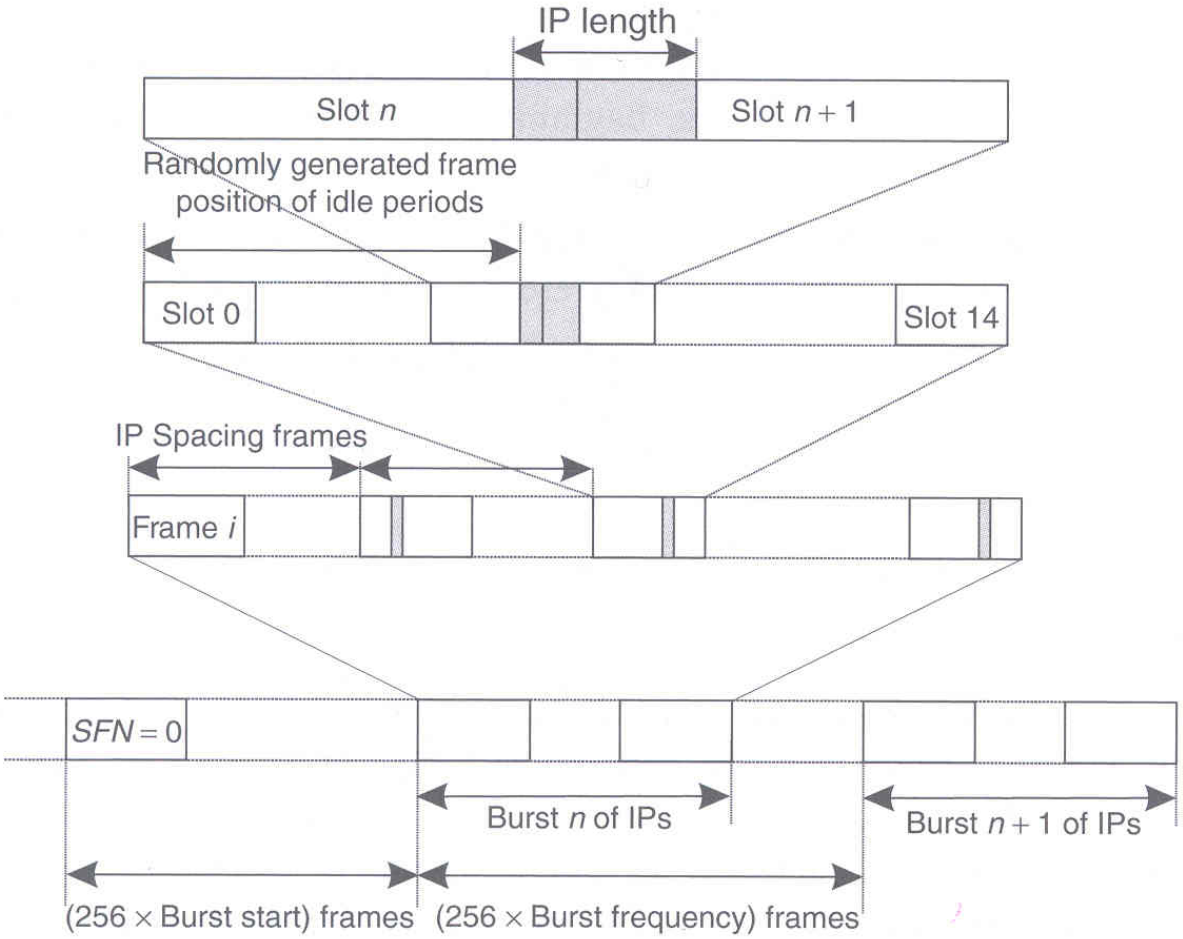

Figure 8.26 Placement of idle periods.

8.3 Assisted GPS in GSM and UMTS

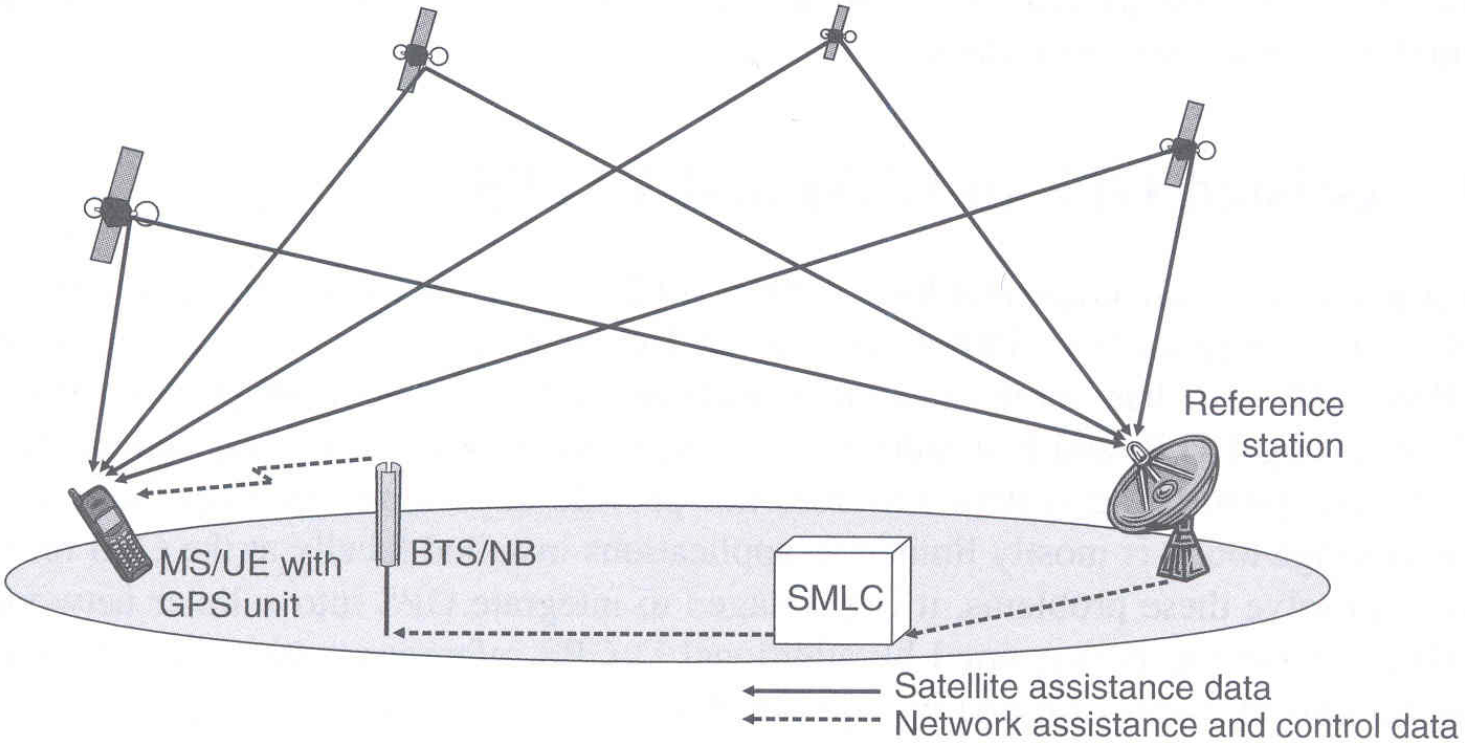

Figure 8.27 A-GPS infrastructure.

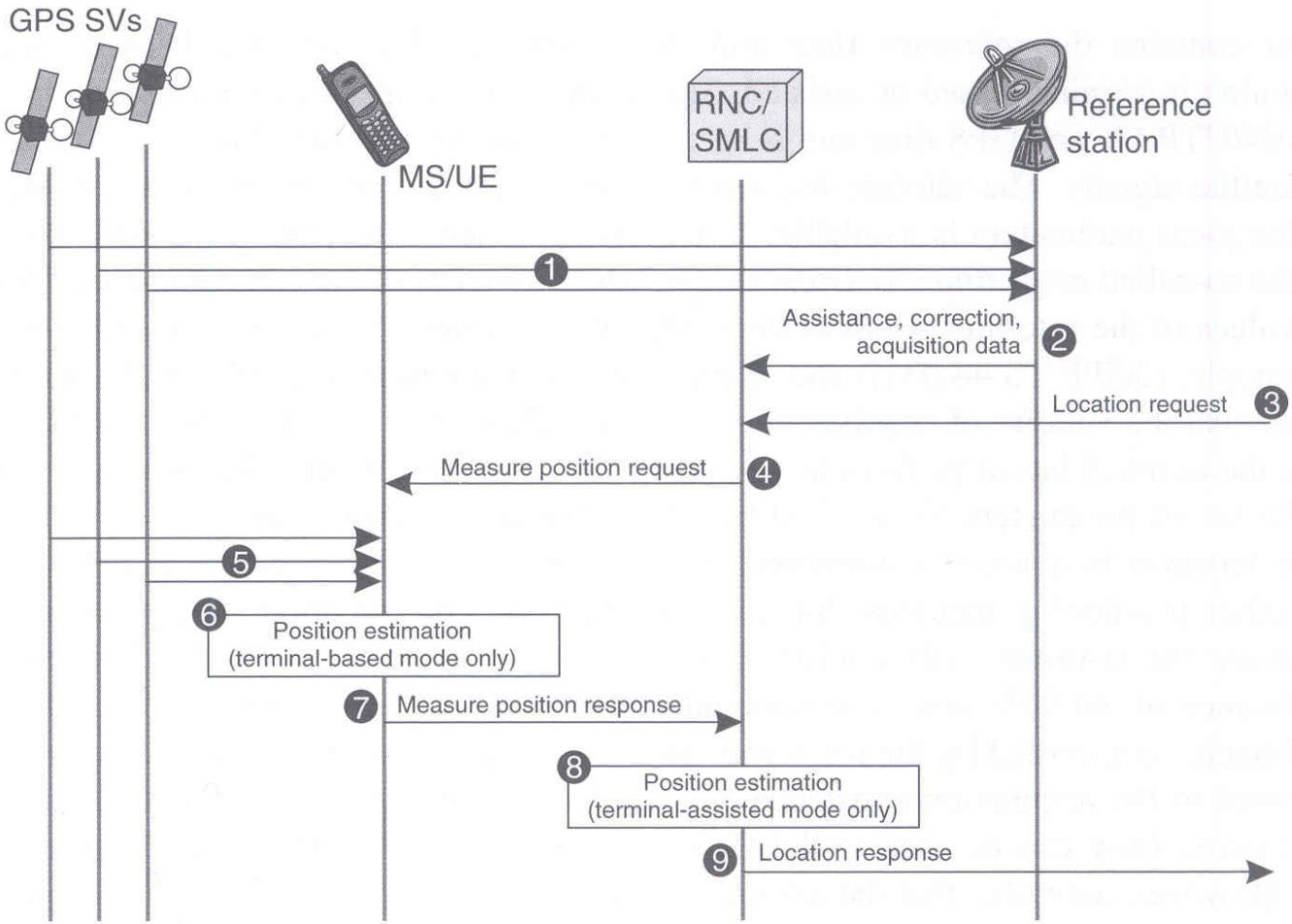

Figure 8.28 Overview of the A-GPS positioning process.

Table 8.12 A-GPS parameters of a position measure request

Parameters	**Terminal-assisted**	**Terminal-based**
Reference time	×	×
Visible satellite list	×	×
Acquisition assistance data	×	
Reference location		×
Satellite ephemeris and clock corrections		×
Almanac		×
D-GPS corrections		×

Table 8.13 A-GPS parameters of a position measure response

Parameters	**Terminal-assisted**	**Terminal-based**
Reference time	×	×
MS/UE position		×
MS/UE velocity		×
Pseudorange	×	
Doppler shift	×	
Signal-to-interference ratio	×	
Pseudorange RMS error	×	
Multipath indicator	×	
Number of pseudoranges	×	

8.4 Positioning in other Cellular Systems

8.5 Conclusion

Table 8.14 Performance characteristics of cellular positioning methods

	Accuracy			Consistency	Yield
	Rural	Suburban	Urban		
Cell-Id	>10 km	2–10 km	50–1,000 m	Poor	Good
E-OTD & OTDoA	50–150 m	50–250 m	50–300 m	Average	Average
U-TDoA	50–120 m	40–50 m	40–50 m	Average	Average
A-GPS	10–40 m	20–100 m	30–150 m	Good	Good

Table 8.15 Other features of cellular positioning methods

	TTFF	Terminal	Overhead	Costs
Cell-Id	approx. 1 s	No changes	Very low	Very low
E-OTD & OTDoA	5–10 s	Dedicated software	Medium/high	High
U-TDoA	5–10 s	No changes	Medium	Medium
A-GPS	5–10 s	Dedicated software and hardware	Medium/high	Low to medium