WiMAX 802.16e timing requirements & TimeMAX

Synchronization needs in 4G

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Outline

- Background & WiMAX overview
- OFDM and WiMAX
- OFDM TDD frame structure
- Interference
- TTG and RTG
- Synchronization drift calculations
- TimeMAX
  - Value proposition
  - Specifications and features
- Summary

For the purposes of this presentation WiMAX implies mobile WiMAX (i.e. 802.16e)

Motivation for Mobile WiMAX

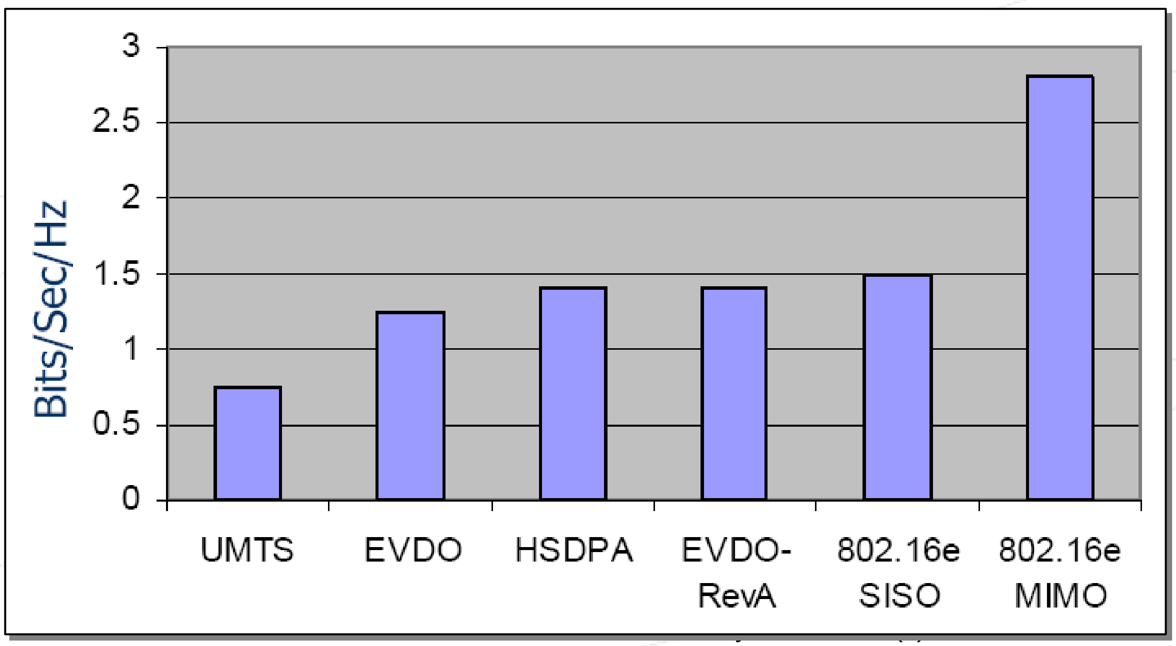
Symmetricom

- **Built-in QoS** – optimal scheduling of space / frequency / time
- **Scalability** – designed to work with different channelizations schemes
- **Best-in class security** EAP / AES authentication / encryption
- **Mobility** – real-time "feel" with < 50msec handover, essential to (secure) VoIP
- **Services** – Data, voice (VoIP), and streaming video

WiMAX (802.16e) will be the 1st truly global mobile broadband standard 4G wireless technology

Technology Overview

- Non line of sight, up to 4-6 mbps per user for a few km
- 2.5 GHz (US), 3.5 & 5.8 GHz licensed bands (rest of the world)
- Channel bandwidth from 1.25 to 20 MHz
- Based on Coded Orthogonal Frequency Division Multiplexing
- TDD for asymmetric traffic and b/w allocation as per need
- Advanced Antenna Systems



Comparison of spectral efficiency

Src: WiMAX forum

Standards

- Existing Standards
  - 802.16 (2004) Air interface for fixed wireless broadband
  - 802.16e (ratified Dec '05) Amendment 2: Physical and media access control layers for combined <u>fixed and mobile operation</u> in licensed bands
- Sync requirements for FDD & TDD
  - FDD – Sync requirement is frequency only

    Available spectrum split into uplink and downlink frequency channels
  - TDD – Sync requirements are time and frequency

    Full spectrum divided into timeslots for uplink and downlink traffic. Guard band gaps between uplink and downlink transmission bursts allow BS and SS to "turnaround" from transmit to receive modes of operation without interference.

Standards – details

Symmetricom

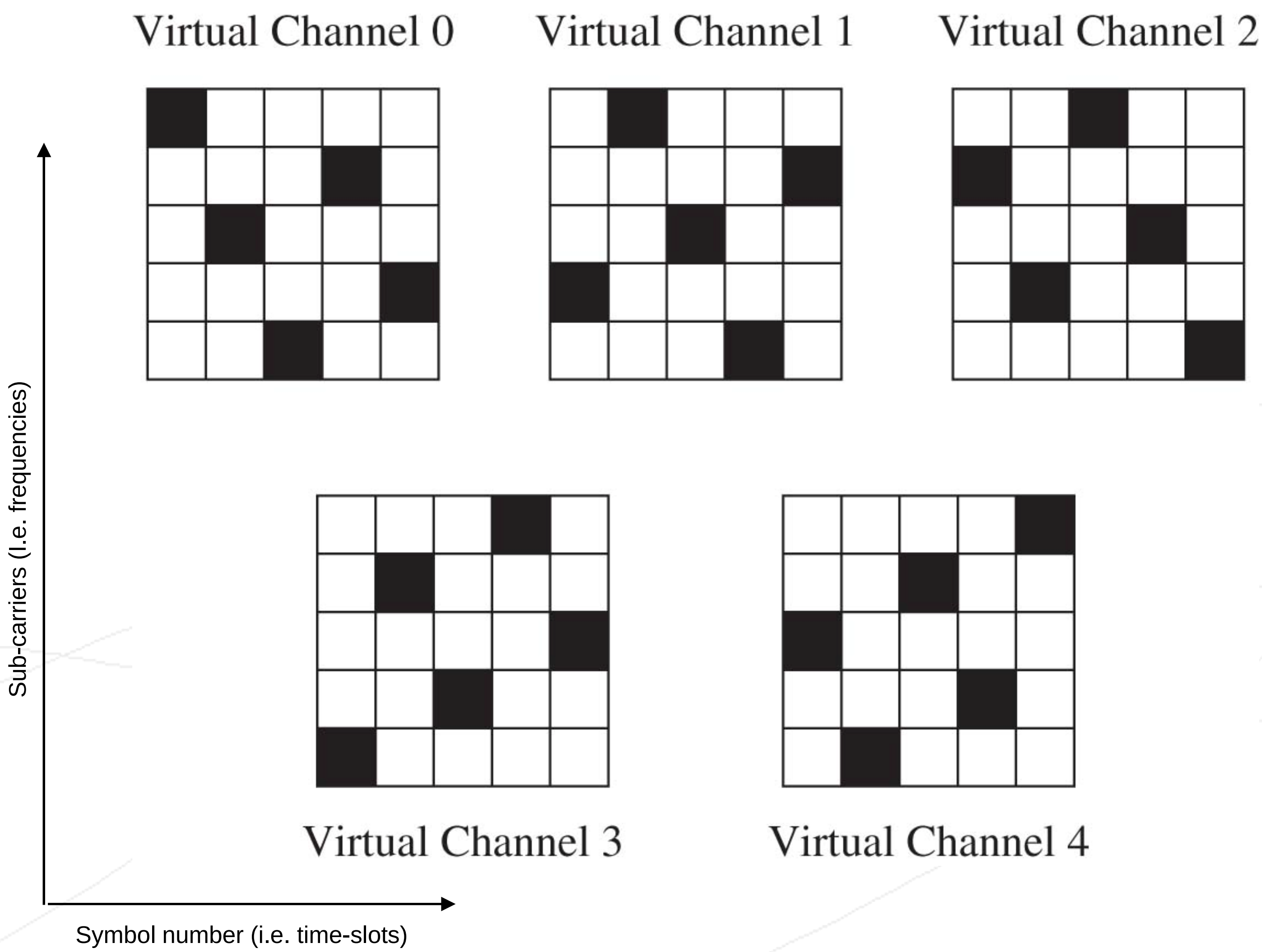
- IEEE 802.16
  - 8.3.7.1.1 Network Synchronization
    - For TDD and FDD realizations, it is recommended that all base stations be time synchronized to a common timing signal. In the event of the loss of the network's timing signal, base stations may continue to operate and shall automatically resynchronize to the network timing signal when it is recovered.
      The synchronizing reference shall be a 1 pps timing pulse.
      A 10 MHz frequency reference may also be used.
      These signals are typically provided by a GPS receiver.
  - 8.3.12 Frequency and timing requirements
    - At the BS, the transmitted centre frequency, receive centre frequency and the symbol clock frequency shall be derived from the same reference oscillator.
      At the BS the reference frequency tolerance shall be better than **$\pm 8 \times 10^{-6}$ in licensed bands up to 10 years from the date of equipment manufacture.**
- IEEE 802.16e
  - 8.4.12.4 Transmitter reference timing accuracy
    - The start of the preamble symbol, excluding the cyclic prefix duration, shall be time aligned with the **1pps timing pulse with an accuracy of 1µs**.
    - This has been interpreted by some as ± 500 ns and by others as ±1µs

WiMAX is based on OFDM

Coded Orthogonal Frequency Division Multiplexing

- Transmission is over orthogonal frequency sub-carriers (i.e. frequencies)
- May operate in either FDD (frequency division duplexing) and TDD (time division duplexing) modes – 802.16e is operated in TDD mode
- Each frequency sub-carriers are chopped into ‘time-slots’ called “Symbols”
- Symbols are allocated by TDMA (in the TDD mode)
- Symbol time is determined by the channel coherence time

Example of Virtual Channels



How OFDM works

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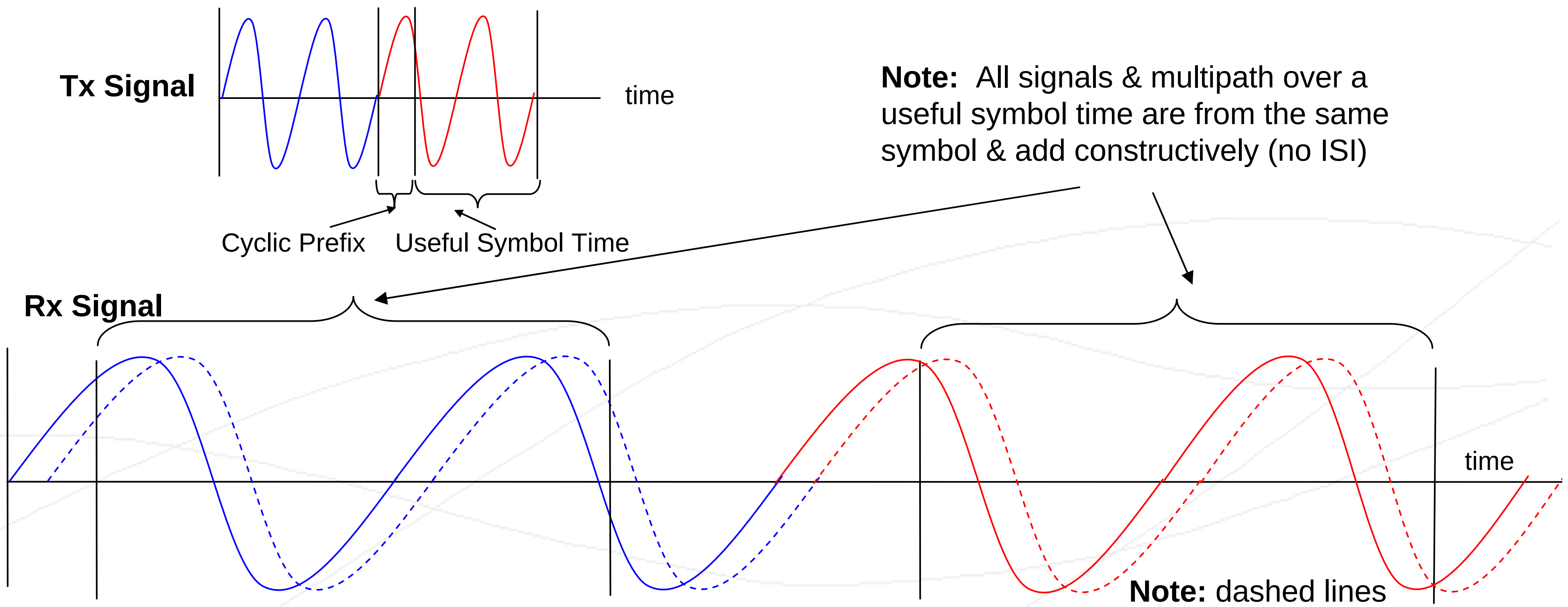
- OFDM overhead = length of prefix / OFDM symbol time
- Length of prefix is dictated by the calculated delay spread
- Basic unit of resource (transmission) is a virtual channel – which is a ‘hopping sequence’
- Each hopping sequence spans all sub-carriers and gets full frequency diversity
- Hopping sequences of different virtual channels in a cell are orthogonal
- Each user is assigned a varying number of virtual channels depending on their data requirement

OFDM

Narrow bandwidth → long symbol times → all significant multipaths arrive within a symbol time minimizing ISI → no equalization → low complexity

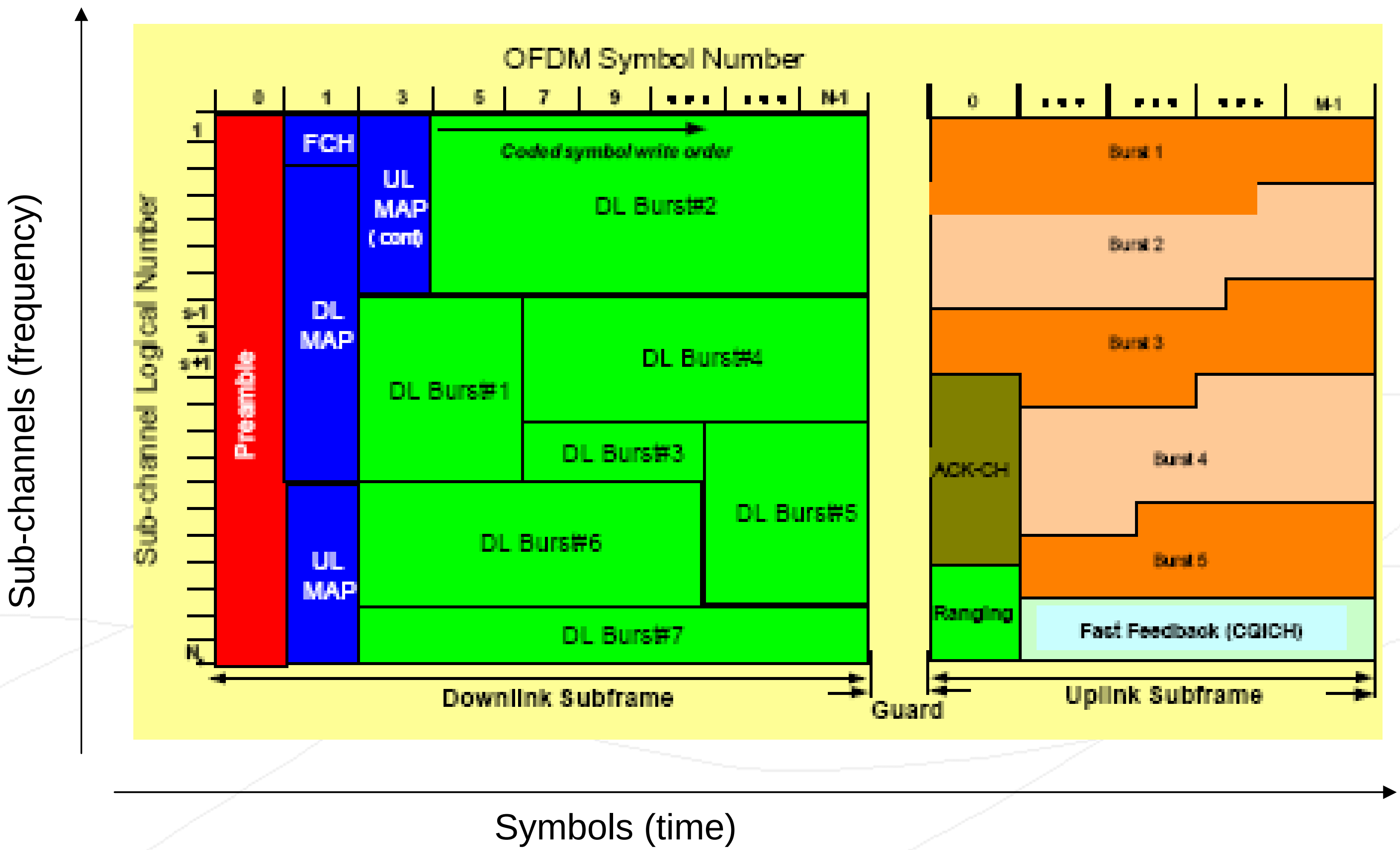


Note: All signals & multipath over a useful symbol time are from the same symbol & add constructively (no ISI)

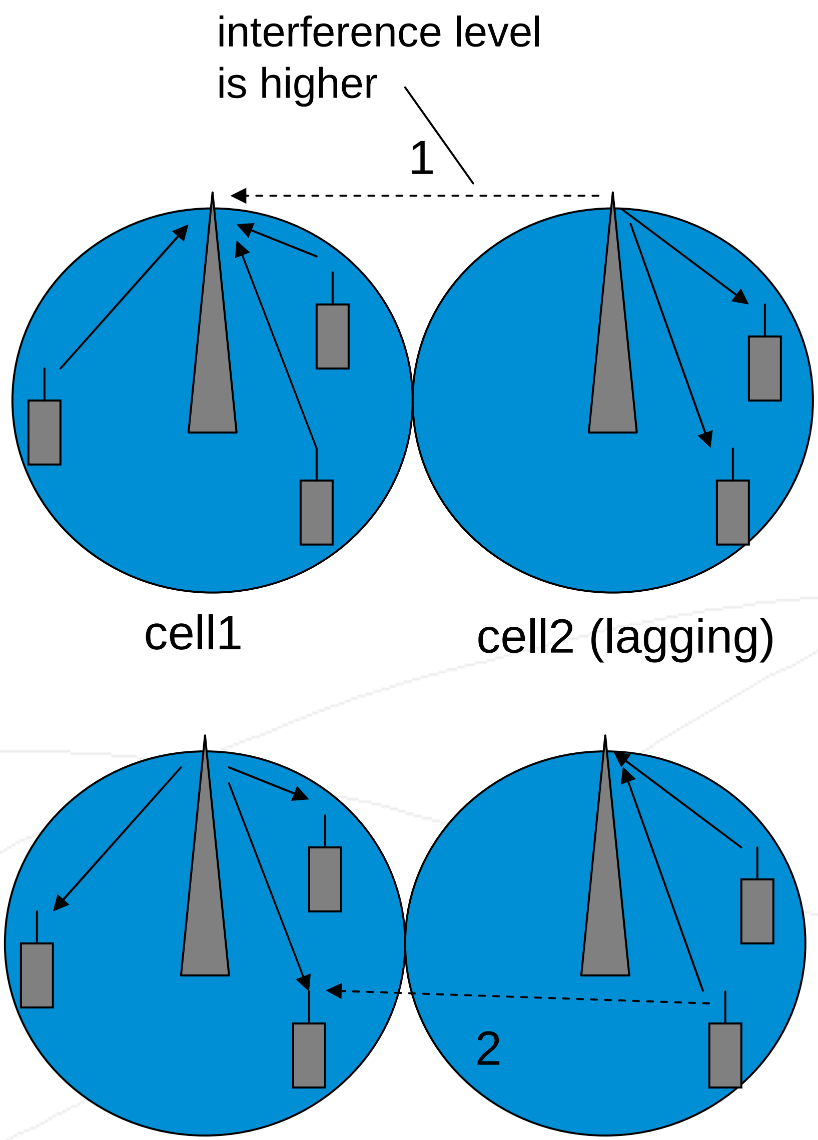
Note: dashed lines represent multipath

Note: ISI = Inter-symbol interference

OFDMA TDD Frame Structure



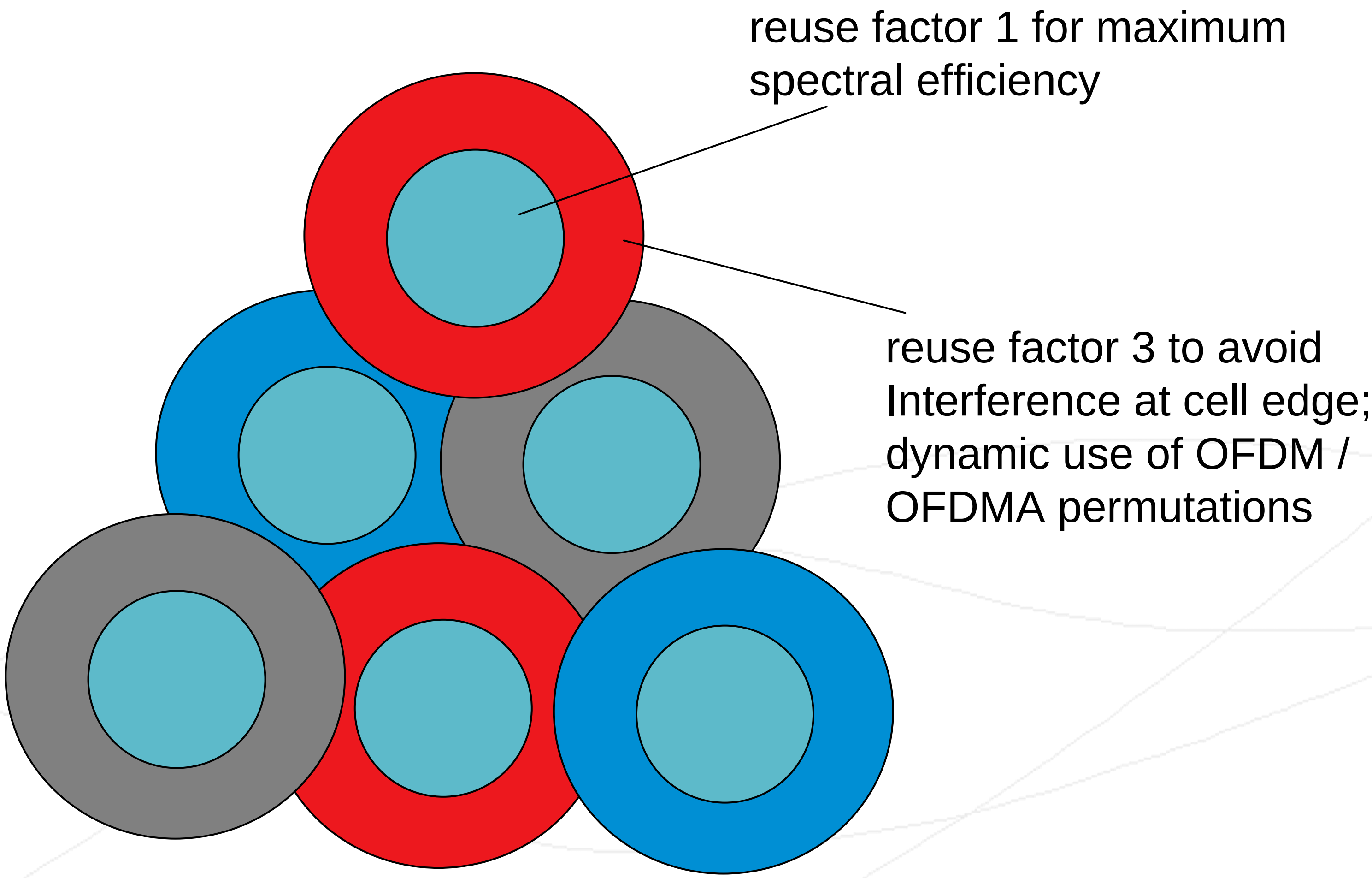
Interference due to drifts



- Two types of interference due to misalignment of downlink/uplink communications
  - Type 1: between base stations
  - Type 2: between mobiles
- Type 1 is more severe because signals will travel far
- Type 2 is of a lesser problem because of higher path loss and OFDMA, two mobiles are likely using different set of OFDM tones
- Therefore, uplink transmissions will be impacted the most (base station interferes with transmitting neighboring base stations)

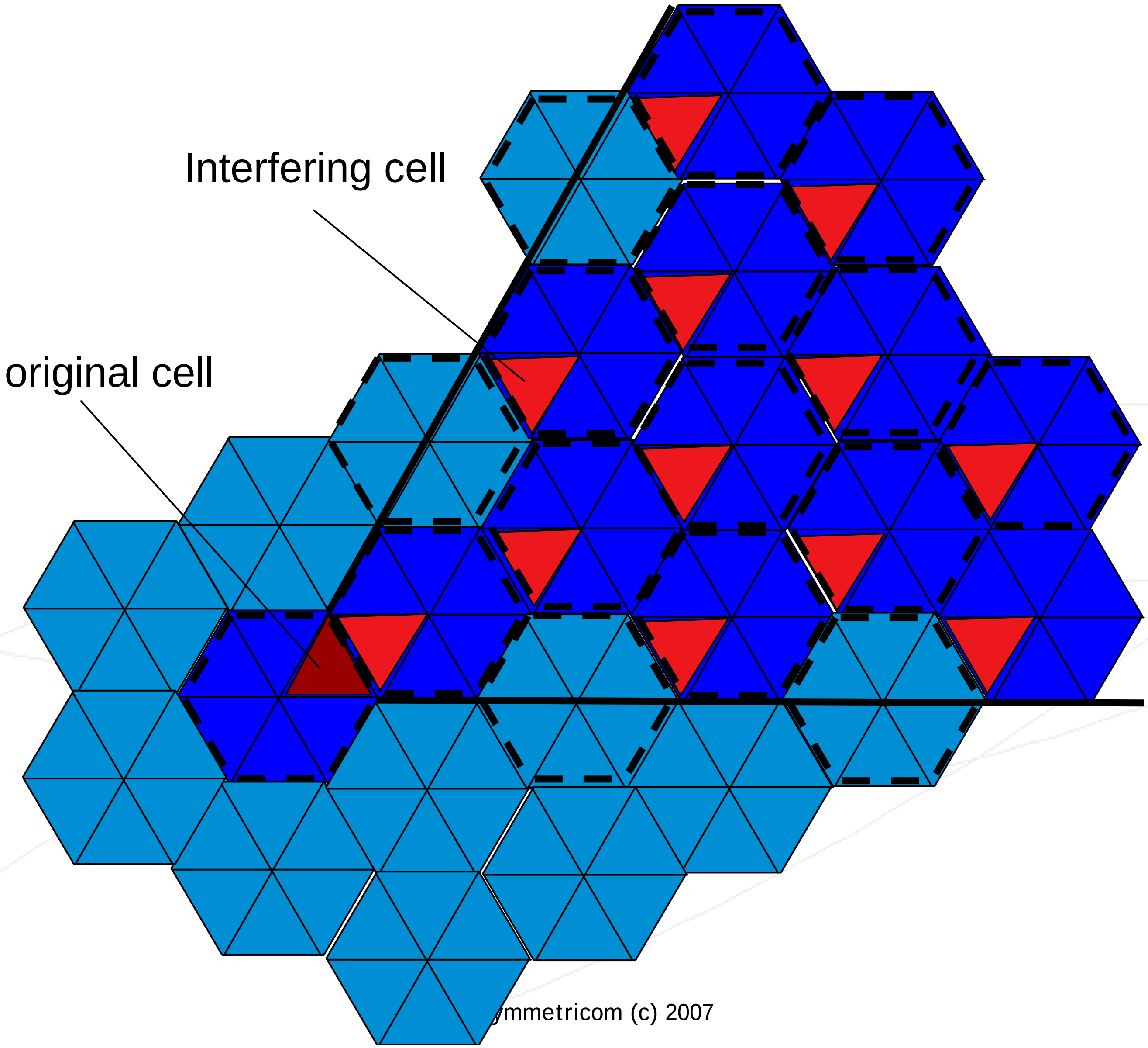
Frequency Reuse in WiMAX

Symmetricom



Reuse at cell edge is **dynamic** using different clusters of subchannels in the band
No need for frequency planning.

Interference from Nearby Cells



Cell Size @ 2.5GHz

Symmetricom

BS Tx power (dBm): 40

BS Tx antenna gain (dBi): 16

Other gains (dB): 2

BS Transmit Power EIRP (dBm): 58

SS Rx sensitivity (dBm): -89 (BPSK)

SS Rx antenna gain (dBi): 0

Wideband/Temporal Fade Margin (dB): 9

Total Link Budget (dB): 58+89+0-9=138 dB

Assuming 10MHz operation (BS/SS antenna height 32/1.5m):

For “free space” (n=2) propagation the signal will travel 76 km

For n=4.07 (Erceg C, flat/light tree density), the distance is **1.4 km**

For n=4.75 (Erceg A, hilly/moderate to heavy tree density), the distance is **0.9 km**

Interference Distance (2.5GHz)

Symmetricom

Cell2 BS Tx power (dBm): 40

Cell2 BS Tx antenna gain (dBi): 16

Other gains (dB): 2 dB

Cell2 BS Transmit Power EIRP (dBm): 58

Cell1 BS Rx sensitivity (dBm): -89 (BPSK)

Cell1 BS Rx antenna gain (dBi): 16

Wideband/Temporal Fade Margin (dB): 9

Total Link Budget (dB): 58+89+16-9=154 dB

"Typical" interference is usually at propagation distance = 6kms; propagation time = 20 µs

This is about 16 dB higher than a downlink (BS-SS) link budget (138 dB for BPSK)

Assuming 10MHz operation (BS antenna height 32m):

For n=4.07 (Erceg C, flat/light tree density), the maximum interference distance is 15.1 km equivalent to about **50 µs**

For n=4.75 (Erceg A, hilly/moderate to heavy tree density), the distance is 3.7 km equivalent to about **12 µs**

Cell Size @ 3.5GHz

Symmetricom

BS Tx power (dBm): 40

BS Tx antenna gain (dBi): 16

Other gains (dB): 2

BS Transmit Power EIRP (dBm): 58

SS Rx sensitivity (dBm): -89 (BPSK)

SS Rx antenna gain (dBi): 0

Wideband/Temporal Fade Margin (dB): 9

Total Link Budget (dB): 58+89+0-9=138 dB

Assuming 10MHz operation (BS/SS antenna height 32/1.5m):

For “free space” (n=2) propagation the signal will travel 54 km

For n=4.07 (Erceg C, flat/light tree density), the distance is **1.1 km**

For n=4.75 (Erceg A, hilly/moderate to heavy tree density), the distance is **0.7 km**

Interference Distance (3.5GHz)

Symmetricom

Cell2 BS Tx power (dBm): 40
Cell2 BS Tx antenna gain (dBi): 16
Other gains (dB): 2 dB
Cell2 BS Transmit Power EIRP (dBm): 58
Cell1 BS Rx sensitivity (dBm): -89 (BPSK)
Cell1 BS Rx antenna gain (dBi): 16
Wideband/Temporal Fade Margin (dB): 9
Total Link Budget (dB): 58+89+16-9=154 dB

"Typical" interference is usually at propagation distance = 4.8 kms; propagation time = 16 µs

This is about 16 dB higher than a downlink (BS-SS) link budget (138 dB for BPSK)

Assuming 10MHz operation (BS antenna height 32m):

For n=4.07 (Erceg C, flat/light tree density), the maximum interference distance is 12.2 km equivalent to about **40 µs**

For n=4.75 (Erceg A, hilly/moderate to heavy tree density), the distance is 3.1 km equivalent to about **10 µs**

Cell Size @ 5.8GHz

BS Tx power (dBm): 30

BS Tx antenna gain (dBi): 16

Other gains (dB): 2

BS Transmit Power EIRP (dBm): 48

SS Rx sensitivity (dBm): -89 (BPSK)

SS Rx antenna gain (dBi): 0

Wideband/Temporal Fade Margin (dB): 12

Total Link Budget (dB): 48+89+0-12=125 dB

Assuming 10MHz operation (BS/SS antenna height 32/1.5m):

For "free space" (n=2) propagation the signal will travel 7 km

For n=4.12 (Erceg C, flat/light tree density), the distance is **0.4 km**

For n=4.75 (Erceg A, hilly/moderate to heavy tree density), the distance is **0.3 km**

Interference Distance (5.8GHz)

Cell2 BS Tx power (dBm): 30

Cell2 BS Tx antenna gain (dBi): 16

Other gains (dB): 2 dB

Cell2 BS Transmit Power EIRP (dBm): 48

Cell1 BS Rx sensitivity (dBm): -89 (BPSK)

Cell1 BS Rx antenna gain (dBi): 16

Wideband/Temporal Fade Margin (dB): 12

Total Link Budget (dB): 48+89+16-12=141 dB

"Typical" interference is usually at propagation distance = 1.7 kms; propagation time = 6 µs

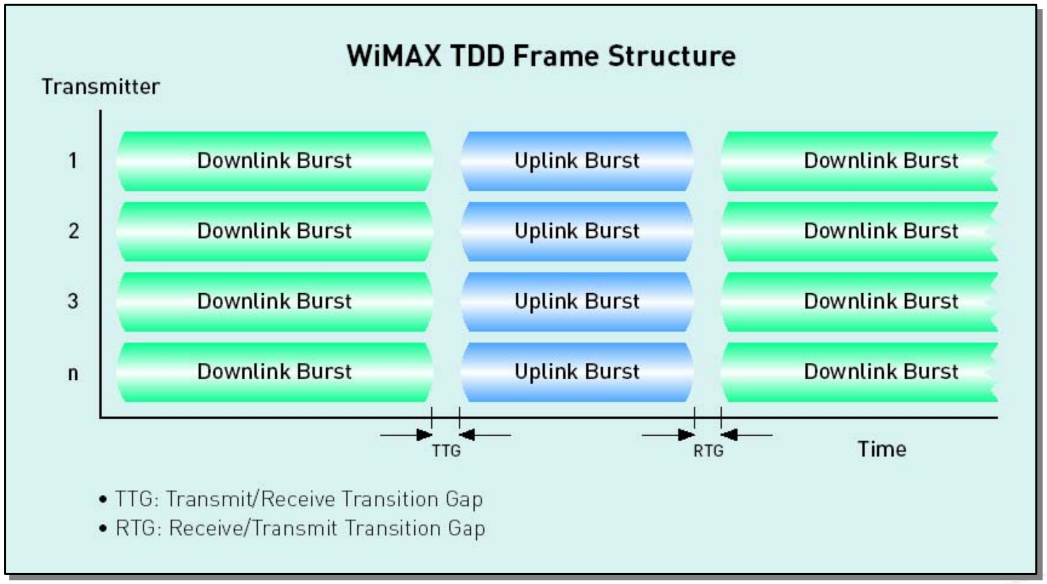
This is about 16 dB higher than a downlink (BS-SS) link budget (125 dB for BPSK)

Assuming 10MHz operation (BS antenna height 32m):

For n=4.07 (Erceg C, flat/light tree density), the maximum interference distance is 4.2 km equivalent to about **14 µs**

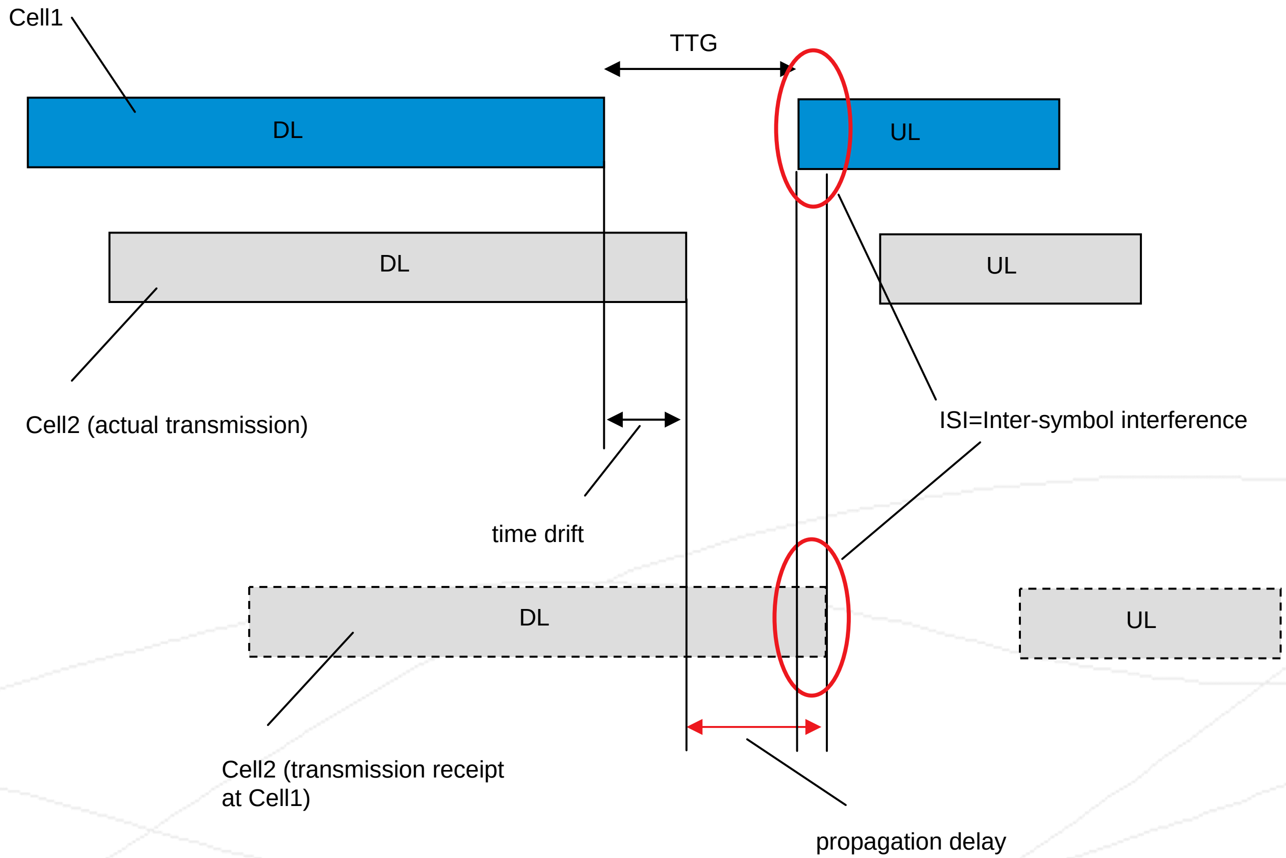
For n=4.75 (Erceg A, hilly/moderate to heavy tree density), the distance is 1.2 km equivalent to about **4 µs**

TTG & RTG considerations



- Standard defines a minimum TTG & RTG of 5 µs
- Typical TTG & RTG ~ 50µs
- Industry examples vary TTG/RTG (87µs - 29µs)
- Must be longer and determined by sum:
  - Tx / Rx switch (turn-around) time; cell size and propagation delays (3.3µs per km apprx.); synchronization drift between base stations
- Larger TTG and RTG mean greater overhead, but less tight synchronization

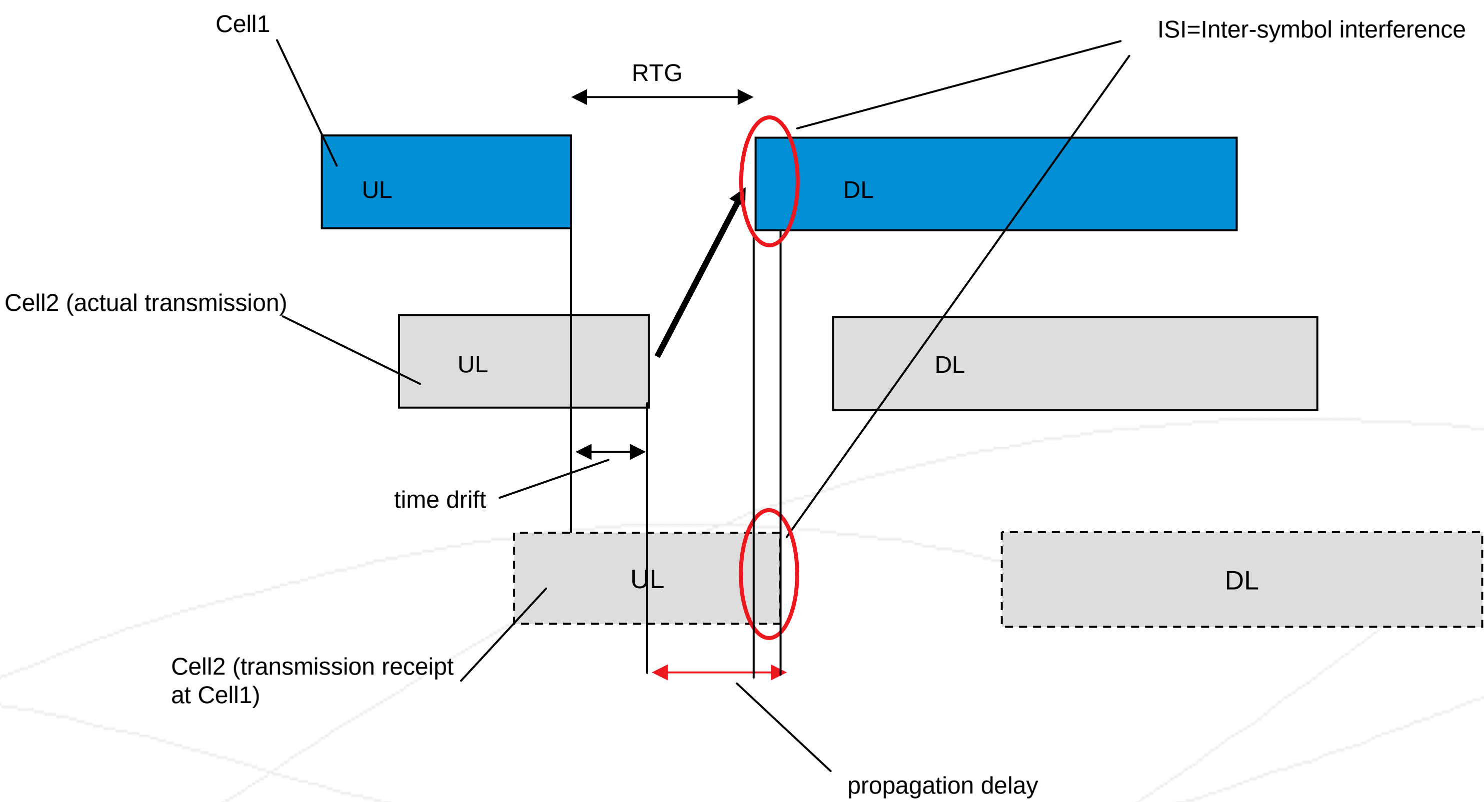
Interference in TTG



TTG must be greater than the total of synchronization (time) drift, switch around (turn-around) time and propagation delay from possibly interfering cells

Type1: BS2 (DL) Affects BS1 (UL)

Interference in RTG



RTG must be greater than the total of synchronization (time) drift, switch around / turn around time and propagation delay from nearby interfering cells

Type2: BS2 (UL) Affects BS1 (DL)

Calculation of Sync Drift

- The propagation delay:
  - The average propagation delay between interfering base stations is calculated on the basis of the diameter of the cell (or distance between the towers)
  - Typical 2.5 GHz cell will have interfering cells' propagation delay of 20 µs
  - Typical 3.5 and 5.8 GHz cells have less propagation delays (16 µs and 6 µs) so, designing for 20 µs is sufficient
- Calculating max synchronization drift so as to avoid interference:
  - TTG / RTG of 50 µs
  - Propagation (typical) delay of 20 µs
  - RTG/TTG consumed by propagation delays = 50 µs - 20 µs = 30 µs
  - Assuming a 5 µs switch around time (transmission to reception)
  - So, the typical allowable synchronization drift = 50 µs – 20 µs – 5 µs = 25 µs
  - A typical 25 µs synchronization drift budget for standard design
- **Symmetricom recommends a maximum drift budget of 25 µs to account for these effects (this is less stringent than the CDMA requirement of 7 µs)**

Sync Drift Discussion

- Symmetricom recommends 25 µs as the optimal synchronization drift
  - This is based on a typical 50 µs
- Different TTG / RTG design specification may require a different synchronization drift specification
  - Some manufacturers design to a more relaxed standard (87 µs) – which will require less stringent sync drift spec
  - Some will have a tighter TTG / RTG – will require more stringent drift spec
- No matter what the specification, GPS based timing is the only way to satisfy the specifications today

Interference Effects

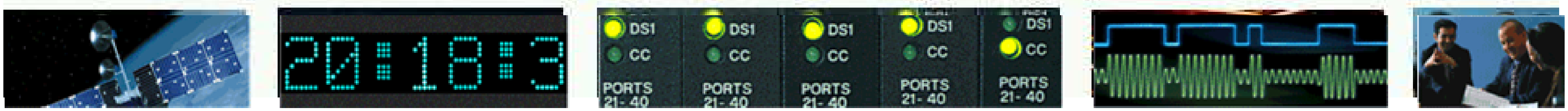
- Low signal to noise ratio (SNR)
- To compensate for this, lower order modulations have to be used (64 QAM → 16 QAM → QPSK) this will lower spectral efficiency
- Low SNR result in receive errors, and trigger re-transmissions
  - Leads to inefficiencies
  - Leads to system malfunction if there are too many re-transmissions

Benefits of Sync in 802.16e

- Maximises BTS efficiency through efficient spectral utilisation
- Optimises frequency utilisation & reuse
- Controls & minimises TTG & RTG
- Effective handover of voice and data sessions for mobility

Summary

- Synchronization drifts that cause overlap of downlink and uplink sub-frames of adjacent cells cause interference
- Time synchronization drifts between base stations effectively reduce TTG and RTG
  - Inefficient if TTG and RTG needs to be increased to accommodate excessive drifts
- TTG and RTG must be greater than the sum of: Propagation delay estimate, turn-around (switch around time) and synchronization drift
- Calculations show that the typical design and deployment require synchronization drift to be less than 25 µs



The TimeMAX subsystem product

Product Details

Applications

- Flexible, simple platform designed to be integrated into communications / transmission equipment
- Accurate GPS referenced time with coherent 1pps and 10 MHz signal
- A low phase noise version (TimeMAX 100LN) for specialized applications
- Some application areas are:
  - WiMAX
  - DVB-H
  - UMTS (for GPS based timing)
  - Satellite communications equipment
  - Other cellular timing needs

Evolution of TimeMAX

- The Starlite family of products is ‘dated’ (last major redesign: 2002)
- No RoHS compliant roadmap
- Form factor too large for today’s applications
- Different performance levels of TimeMAX offered, appropriate for different market requirements

Value Proposition

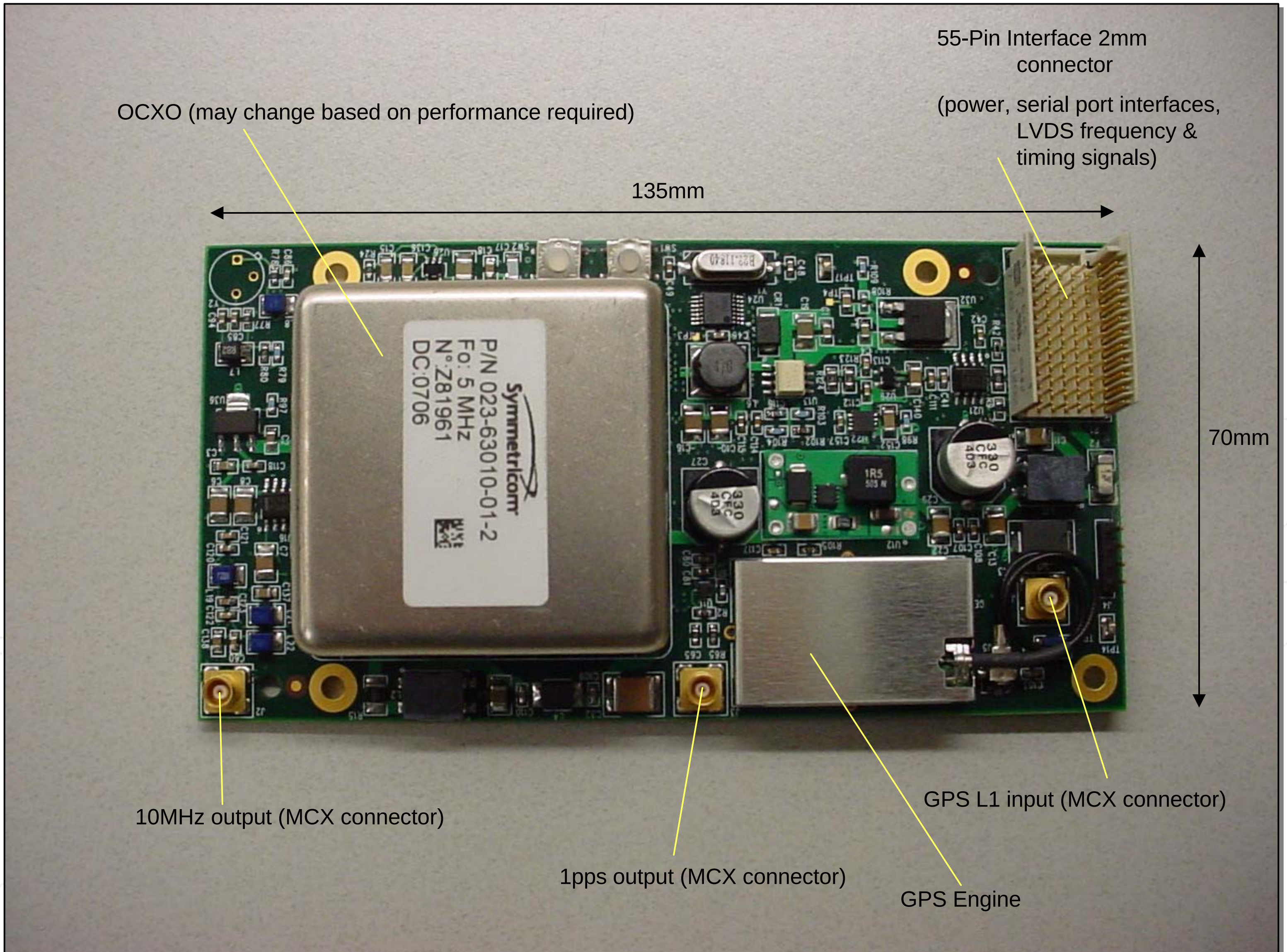
- Clean up GPS short term and medium term stability
  - 20 ns peak to peak for TimeMAX vs 300 ns peak to peak for commercial GPS receivers
- Holdover performance becomes a need as the application sees “real” field deployment
  - Interference at antenna sites causes GPS reception to fail (especially RF bursts)
  - Satellite view may be impeded at regular intervals in urban canyons and other such impediments
  - Required rapid response to failures ramps up operational costs resulting customer complaints and loss of revenue / business

Technical Innovations

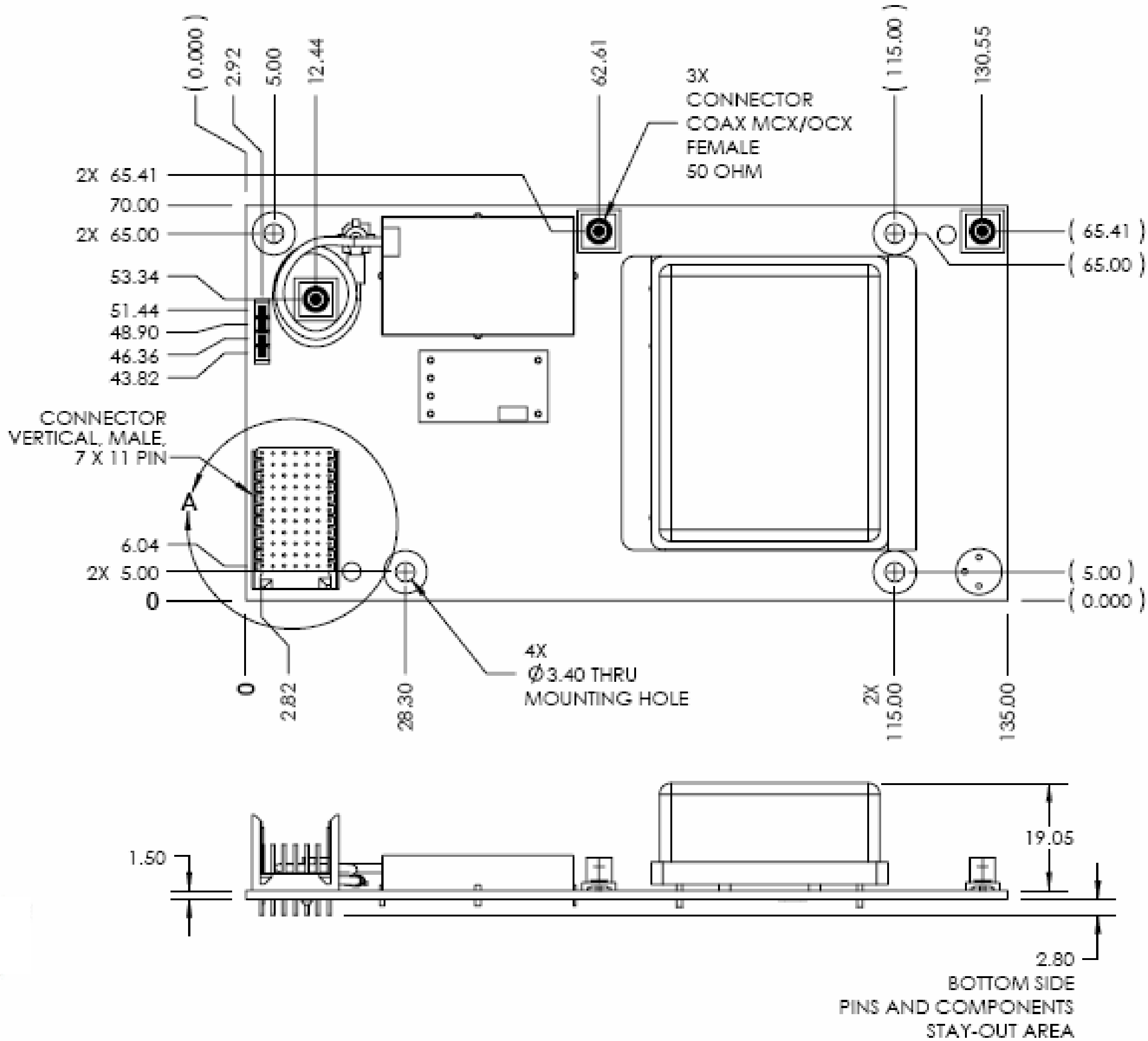
Symmetricom

- Algorithms for noise reduction of GPS
- Algorithms enhancing short & long term stability of oscillator (SmartClock® technology)
- Optimal thermal and mechanical design for wide operating temperature range & temperature ramps
- Modeling GPS ON/OFF periods through algorithms for stable output signals

TimeMAX™


55-Pin Interface 2mm connector
(power, serial port interfaces, LVDS frequency & timing signals)
OCXO (may change based on performance required)
135mm
70mm
10MHz output (MCX connector)
1pps output (MCX connector)
GPS Engine
GPS L1 input (MCX connector)

Mechanical Drawing



Specifications Summary

- Inputs
  - GPS L1
- Outputs
  - 1pps TTL & L VDS
  - 10 MHz TTL & LVDS
  - Serial ports: RS232 & RS422
- Operating temperature range: -10°C to +65°C
- Communication Protocol
  - SCPI: Standard Command for Programmable Instrumentation
- Power:
  - 12V DC, 12W Max, 7.5W steady state
- Physical Size:
  - 135mm L X 70mm W X 20mm H
  - 5.3” X 2.76” X 0.79”

Portfolio

Symmetricom

Standard 10MHz & 1pps Technology Platform

Superior holdover & phase noise performance:

Customers designing to ~30 µs TTG / RTG

TimeMAX 400LN

Phase noise:

- -82 dBc/Hz max. at 1 Hz offset
- -120 dBc/Hz max. at 10 Hz offset
- -140 dBc/Hz max. at 100 Hz offset
- -145 dBc/Hz max. at 1 kHz offset
- -150 dBc/Hz max. at 10 kHz offset
- -150 dBc/Hz max. at 100 kHz offset

Holdover:

<8 µs over 24 hrs at 50°C

P/N: 090-03860-41

Superior holdover performance:

Customers designing to ~30 µs TTG / RTG

TimeMAX 400

Phase noise:

- -120 dBc/Hz max at 100 Hz offset
- -140 dBc/Hz max at > 1Hz offset

Holdover:

<8 µs over 24 hrs at 50°C

P/N: 090-03860-40

Superior phase noise performance

TimeMAX 100LN (superior phase noise performance)

Phase noise:

- -82 dBc/Hz max. at 1 Hz offset
- -120 dBc/Hz max. at 10 Hz offset
- -140 dBc/Hz max. at 100 Hz offset
- -145 dBc/Hz max. at 1 kHz offset
- -150 dBc/Hz max. at 10 kHz offset
- -150 dBc/Hz max. at 100 kHz offset

Holdover:

<1 µs over 2 hours (over 1°C temp change) (typical)

P/N: 090-03860-11

Summary

- Mobile WiMAX (802.16e) requires synchronization & holdover technology
- GPS with holdover is the recommended source for synchronization for WiMAX base stations today
- Recommended holdover: 25 µs for 24 hrs
- TimeMAX offers a high value, simple packaged sub-system solution
- Customization of TimeMAX on case by case basis