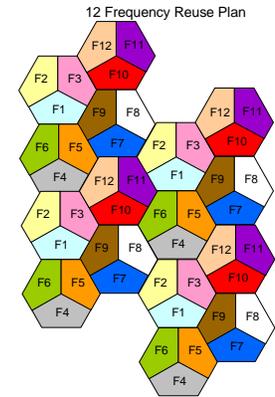


**R1-063056: Uplink Reference Signal Multiplexing
for E-UTRA
Agenda Item: 6.4.2**

Two major issues

- **What is minimum RS BW, and how many uplink RS sequences are required between cells?**
 - Primary driver for considering CDM is GCL/CAZAC sequence length
 - **12sc RB size places fundamental limit on sequence length**
 - 12sc RB → length 6 sequence, 6 sequence available
 - From Motorola R1-061720, 12 sequences may be enough ...
- **How will distributed sounding RS be supported in addition to data demodulation RS?**
 - **Current working assumption:**
 - FFS whether to send them statically/dynamically, and how to multiplex
 - **Should the design have no sounding overhead if sounding is not used? (the primary mode of operation varies between different companies)**
 - **Options include**
 - No channel dependent scheduling (no sounding)
 - Selective use of an LB if sounding desired
 - Sounding multiplexed separately (e.g., via FDM) on one or both short blocks
 - Sounding multiplexed together (e.g., via CDM) on one or both short blocks
 - Scanning of sounding RS to enable broadband sounding
- **It is difficult to progress UL RS design without addressing these issues (aspects of the design are inter-related)**



Summary

- **Next several slides explore the tradeoffs of the different options**

- **Option 1a appears promising due to the following characteristics**
 - **Data demodulation RS BW = data BW**
 - Provides the highest possible power spectral density on data demodulation pilot (beneficial for range-limited scenario)
 - **Selective use of LB for sounding RS**
 - No overhead when sounding not present
 - Acceptably small overhead for sounding when present
 - For minimal overhead, we suggest that a non-sounding UE be allowed to Tx data on a sounding LB (e.g., if the sounding is on every 2nd subcarrier)
 - **Best data demodulation channel estimation performance for intra-TTI frequency hopping**
 - Both SBs within a hop are available for data demodulation and are of equal quality
 - **Improved edge-of-sector channel estimation performance**
 - Cyclic shifts of one sequence can be allocated among sectors of the same Node-B, thus providing near-orthogonality between RS of adjacent sectors
 - Same concept is already supported for DL RS

Summary - continued

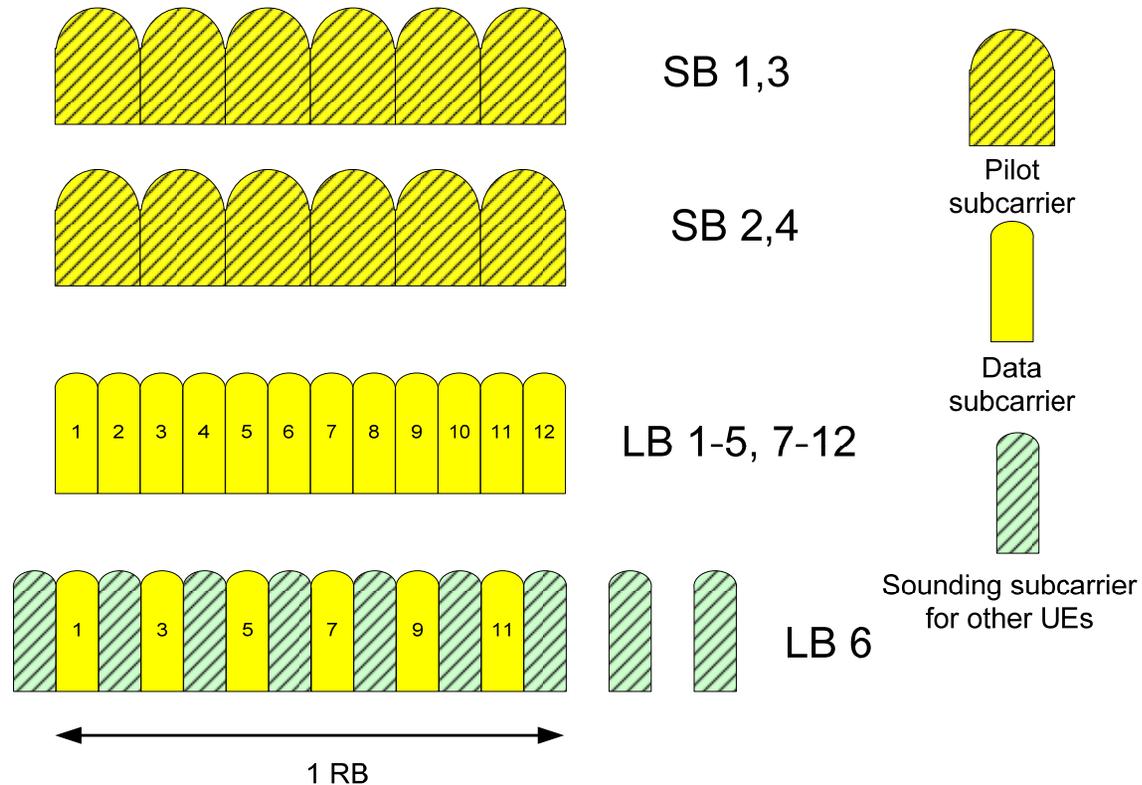
- **Suggested way forward (based on Option 1a)**
 - **SB RS BW = data BW on all SBs**
 - **Sequence reuse among cells**
 - Baseline tools: different root sequences, different cyclic shifts of the same root sequence, and Walsh coding across SBs within a subframe
 - Additional tools (sequence hopping, etc.) are FFS
 - **Selective use of LB for sounding RS**
 - Sounding can be dynamically turned on or off, and have adjustable spacing in time for overhead management
 - Position of LB for sounding within a TTI (when present) is FFS
 - Best position depends on the scheduling turnaround time and frequency of sounding in time
 - It should be possible to allocate only a fraction of the LB subcarriers for sounding
 - Example 1: exclude some band-edge RBs from sounding to improve OOB emissions
 - Example 2: exclude some band-edge RBs due to UL control channel occupying those RBs
 - Example 3: exclude a set of subcarriers from sounding to allow a non-sounding UE to transmit data on some of the subcarriers of a sounding LB (e.g., every 2nd subcarrier of the LB is used for sounding RS)
 - **Sounding RS of differing BW are multiplexed by FDM**
 - ~ 4 sounding BWs should be supported
 - **Sounding RS of same BW but on different RBs are multiplexed by FDM**
 - **Sounding RS of same BW and spanning same RBs are multiplexed by CDM or FDM**

Potential “Ways Forward” – Option 1

- **Option 1: Selective use of a LB for sounding**
 - Sounding RS (if present) can be CDM or FDM on a LB
 - Can use part of an LB (e.g., every other subcarrier) to reduce overhead
 - *Clean design: Adjustable sounding BW, and no overhead if sounding not used*
 - Example: 1 Sounding LB every 4th TTI: 1% overhead

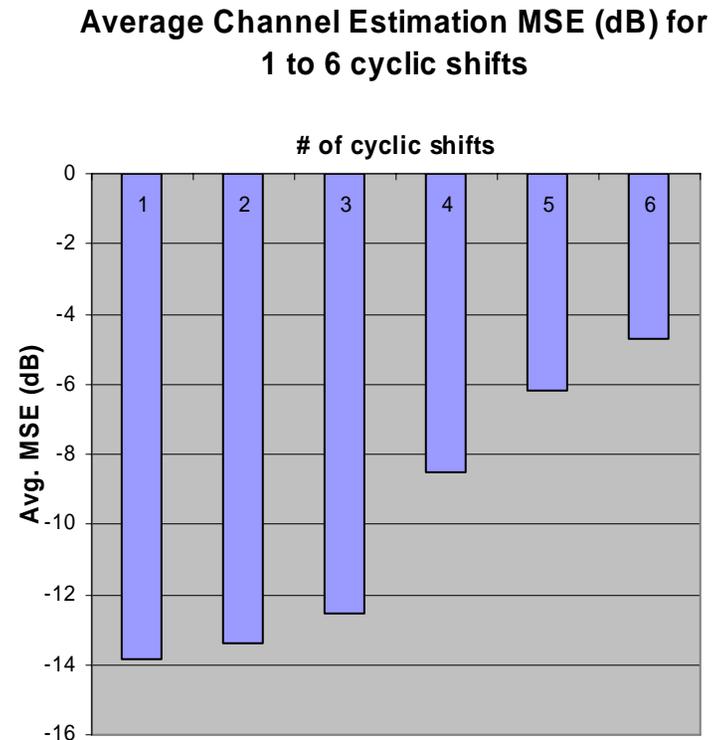
- **Configuration 1a**

- RS BW = RB BW for localized RB
- **Results in RS sequence length of 6**
- *K* cyclic shifts of the 6 root sequences can be used increase the number of available sequences for planning
- Sequence and cyclic shift reuse issues highlighted on next slides



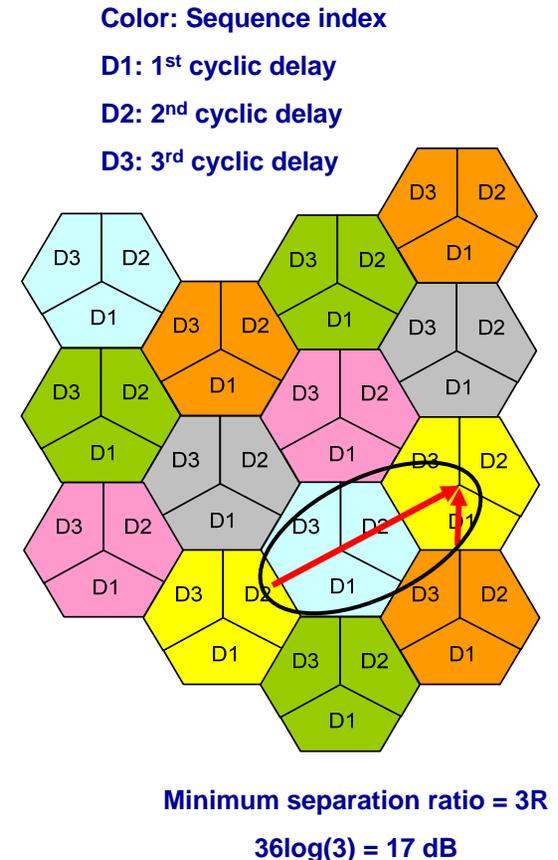
How many cyclic shifts are practical?

- For a pilot sequence length of 6, can 6 cyclic shifts ($K=6$) really be supported?
 - Figure shows channel estimation MSE for 1 to 6 cyclic shifts
 - TU 6 ray channel, 10 dB SNR
 - True MMSE channel estimator, weights optimized for each subcarrier
 - Results indicate 3 shifts can be supported with small degradation
 - Link simulations (FER) have similar trends as CE MSE results



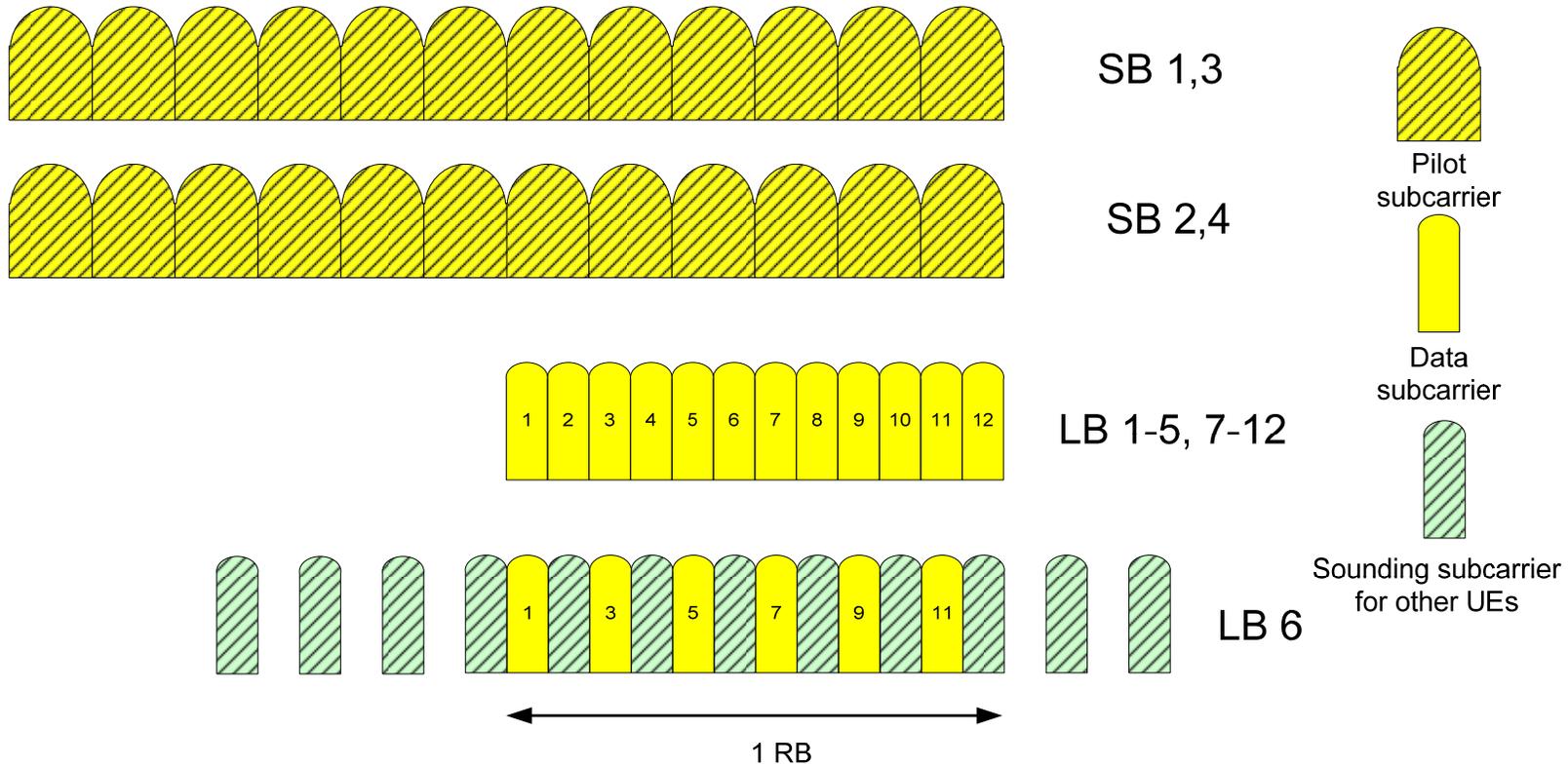
Sequence Reuse Discussion for Option 1, Config. 1a

- **Configuration 1a: localized 1 RB FDM pilot**
 - Sequence length = 6 for 1 RB allocation
 - Number of cyclic shifts for 1 RB allocation ~3 (without coding over multiple SBs)
 - $K=3$ from previous slide
 - Possible assignment strategies
 - Assign the 3 cyclic shifts of one sequence to one Node B (3 sectors)
 - Assign different sequences (6 available) to different Node-Bs (see one example in right-side figure)
 - Issue: no cyclic shift available for UL MIMO/SDMA
 - Possible Resolutions
 - Use all 6 cyclic shifts (instead of 3) so that each sector gets 2 cyclic shifts
 - » Mitigate the interference between shifts by encoding over two SBs (e.g., Walsh coding)
 - Increase the minimum assignment size for UL MIMO/SDMA to 2 RBs
 - » Sequence length of 12 will enable ~ $K=4$ cyclic shifts (or 6-8 with coding over 2 SB)



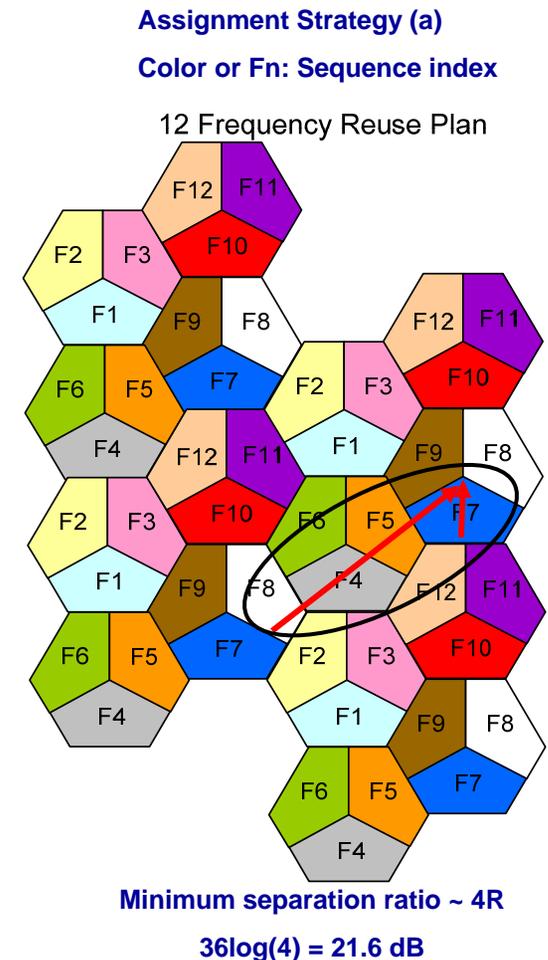
Option 1, Configuration 1b

- Configuration 1b: RS BW > 1 RB (e.g., 2 RB)
 - Results in minimum RS sequence length of 12
 - K cyclic shifts of the 12 root sequences can be used increase the number of available sequences for planning
 - Sequence and cyclic shift reuse issues highlighted on next slides



Sequence Reuse Discussion for Option 1, Config. 1b

- **Config. 1b example: 2 RB minimum BW pilot**
 - **Sequence length = 12 for 1 RB data allocation**
 - Pilot BW = max(2 RB, number of data RBs allocated)
 - **Number of cyclic shifts for 1 RB allocation ~4 (without coding over multiple SBs)**
 - **Possible assignment strategy (a)**
 - Use all 4 cyclic shifts in one cell (cell=sector): 2 for adjacent 1 RB data allocations, and 2 for UL MIMO/SDMA
 - Assign different sequences (12 available) to different cells
 - **Possible assignment strategy (b)**
 - Use 2 cyclic shifts per sector (for EITHER adjacent 1 RB data allocations, OR UL MIMO/SDMA over 2 RB) x 3 sectors per Node B = 6 cyclic shifts
 - To reduce interference between the cyclic shifts, code over multiple SBs (e.g., Walsh coding)
 - Assign different sequences (12 available) to different Node Bs
 - **Issue: 3 dB reduced power density on pilot compared to data (1 RB allocation). Simulations to determine impact.**



Option 1 – Summary

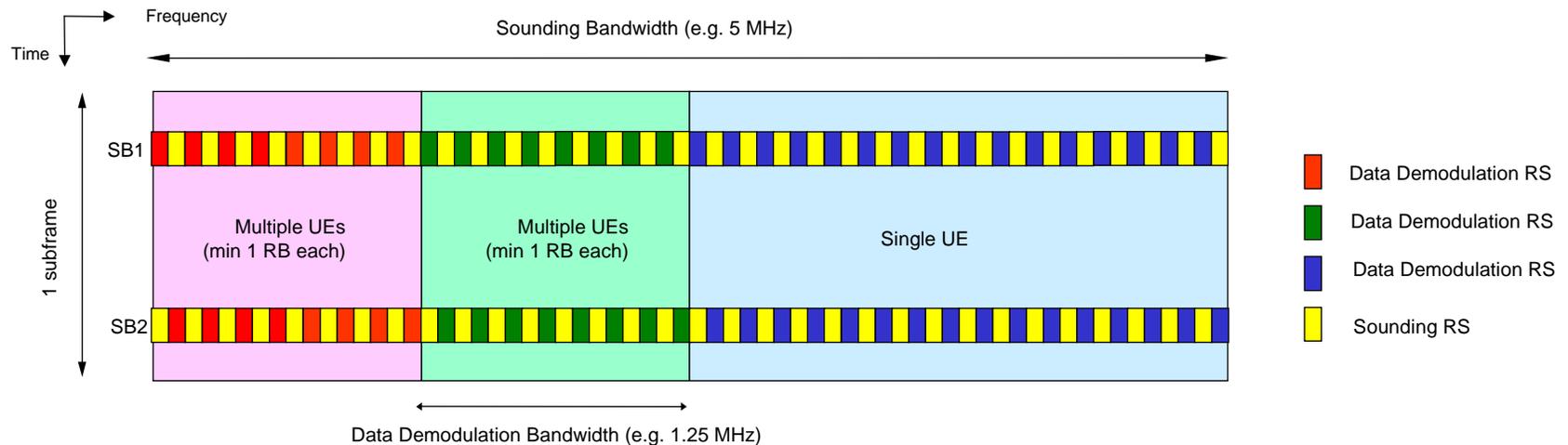
- **Acceptably small overhead for sounding when present**
- **No overhead when sounding not present**
- **Config. 1a simplest, with highest power spectral density on data demodulation pilot (beneficial for range-limited scenario)**
- **Config. 1b provides more sequences for cell planning**
- **Why not “steal” a SB for sounding? Potential problems include:**
 - **Loss of a data demodulation RS needed by high speed mobiles**
 - **Inability to encode demodulation RS cyclic shifts over 2 SBs**
 - **Losing one of the 2 SBs needed for data demodulation with intra-TTI frequency hopping**
 - **Losing one of the 2 SBs needed for data demodulation in a 0.5 ms single RB allocation**

Potential “Ways Forward” – Option 2

- **Option 2: Data demodulation RS is much wider than resource allocation, additional broadband sounding separately multiplexed on short blocks**
 - **Key observation 1: Sounding and data demodulation RS may be separately multiplexed using every other subcarrier on one (or both) SBs**
 - Variable BW sounding (e.g, up to 20MHz) multiplexed on every other subcarrier
 - ‘Hopping’ an RS on a SB may be unnecessary
 - **Key observation 2: Data demodulation RS may be wider than resource allocation (e.g., nominal 1.25 or 2.5MHz), on every other subcarrier**
 - Allows longer length sequence (and therefore more sequences for planning)
 - Data Demodulation RS provides limited inherent channel sounding capability (not broadband)
 - Some degradation in data demodulation performance from reduced pilot power density

Option 2

- **D = Data Demodulation RS bandwidth (minimum)**
 - E.g. 1.25MHz, 2.5MHz, or 5MHz (nominal)
 - May be equal to channel bandwidth
- **S = Sounding RS bandwidth (configurable)**
 - May equal channel BW
 - May be less than channel bandwidth but greater than D
 - May equal D (if needed for edge of cell users)



#Users and Sequence Length

Nominal Data Demod RS BW (min)	#RBs (12sc)	Max #users	Sequence Length (CDM)
“1.25MHz”	6	6	18
“2.5MHz”	12	6	37
“5MHz”	25	6	75

- With RS on every other sc, 6 users RS are separable with 5.56us shifts (either CDM with Walsh over 2 SBs, or FDM)
 - Issue: not enough shifts for 6 UL MIMO or 6 + 6 UL SDMA users
 - Resolution: Minimum data allocation for UL SDMA/MIMO is 2 RBs
- 18 sequences for planning (all the cyclic shifts are used up intra-cell)
- 2.5MHz with small 12sc RB restricts scheduler to max 6 users in 12 RB
- Minimum transmit BW of 1.25 MHz or more may have edge-of-cell or OOB problems (FFS)

Data Considerations

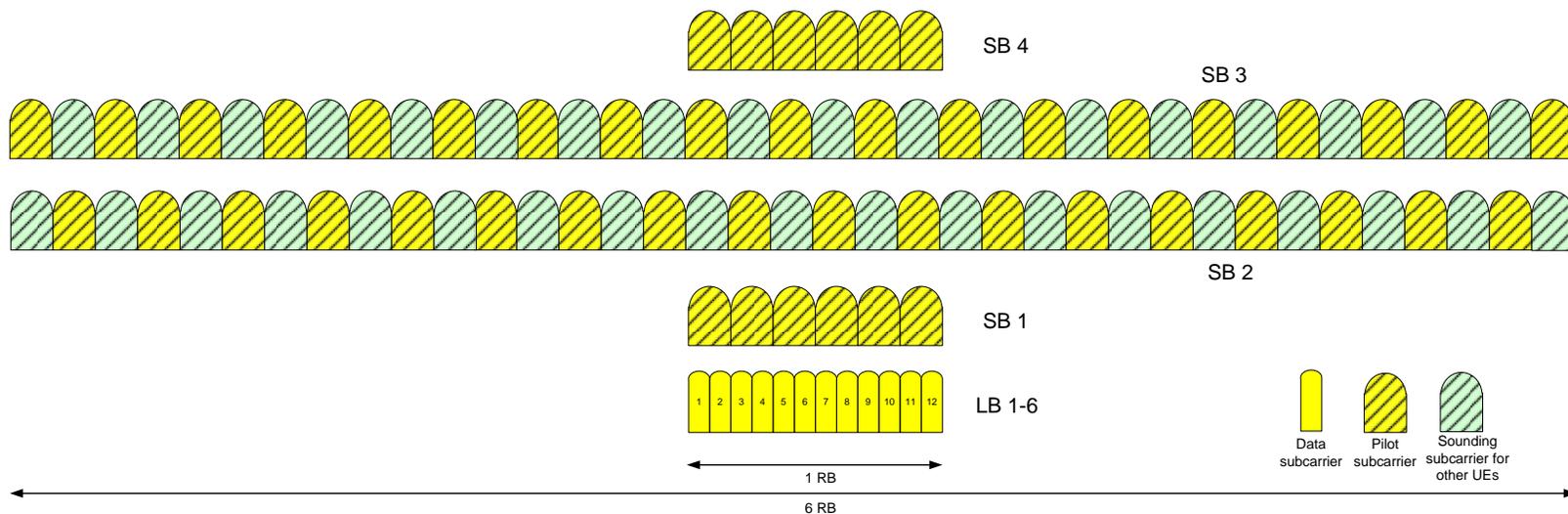
- **Degradation for $D=1.25\text{MHz}$ $\sim 0.5\text{dB}$ (localized allocation, R1-061721)**
- **Allowed RB allocations**
 - **Within the $D = \text{Data Demodulation RS Bandwidth}$, users can be allocated in 1 RB increments, preferably multiple of 2 or 3 for efficient DFT implementation**
 - $D = 1.25\text{MHz}$, 1 to 6 RBs
 - **If more than D is to be transmitted, need to add BW in chunks of D**
 - Data demodulation RS BW increases in chunks of minimum D
 - 1.25MHz has 6RBs, next allocation after 6 RBs is 12 RBs
 - Cannot concatenate 1.25MHz or 2.5MHz pilots at UE and have good CM as repetition in F domain = every other sample in T domain = higher CM
 - Any # of RB can be assigned for data transmission, but may have to leave some RBs empty
 - [Degradation TBD]
- **RS to be used are either explicitly assigned or are known from the order of resource allocation**

Sounding Considerations

- **6 users per S = Sounding RS bandwidth (every other subcarrier used)**
 - **CDM with Walsh coding over the 2 SBs likely unnecessary for sounding purposes**
 - 3 users per SB, rather than 6 users coded across both SB
 - **Can edge of cell users do broadband sounding?**
 - Will edge of cell users be FS scheduled?
 - BW or power of sounding could be adjusted
 - **Configuration (signaled in joint control, broadcast control, etc.)**
 - **2 SB sounding RS (as shown)**
 - **No sounding RS: RS on every sc for data demodulation**
 - Best to have $S = D$ (same BW)
 - Having D larger than RB bandwidth only needed for sequence length (# sequences)
 - **Configuring system-wide or per cell is TBD**
 - **(Also, supporting 1 sounding SB rather than on both SBs may add unnecessary complexity – C.E. and signaling)**
- **Broadband sounding may be periodic or explicitly assigned**
 - To get broadband sounding at same time as data transmission can use sounding RS on one SB and leave normal RS on that SB empty (maintain low CM)
- **Due to smaller 12sc RB and 25RBs / 5MHz BW, additional sounding opportunities may be provided by selective use of a LB as in option 1**

Potential “Ways Forward” – Option 3

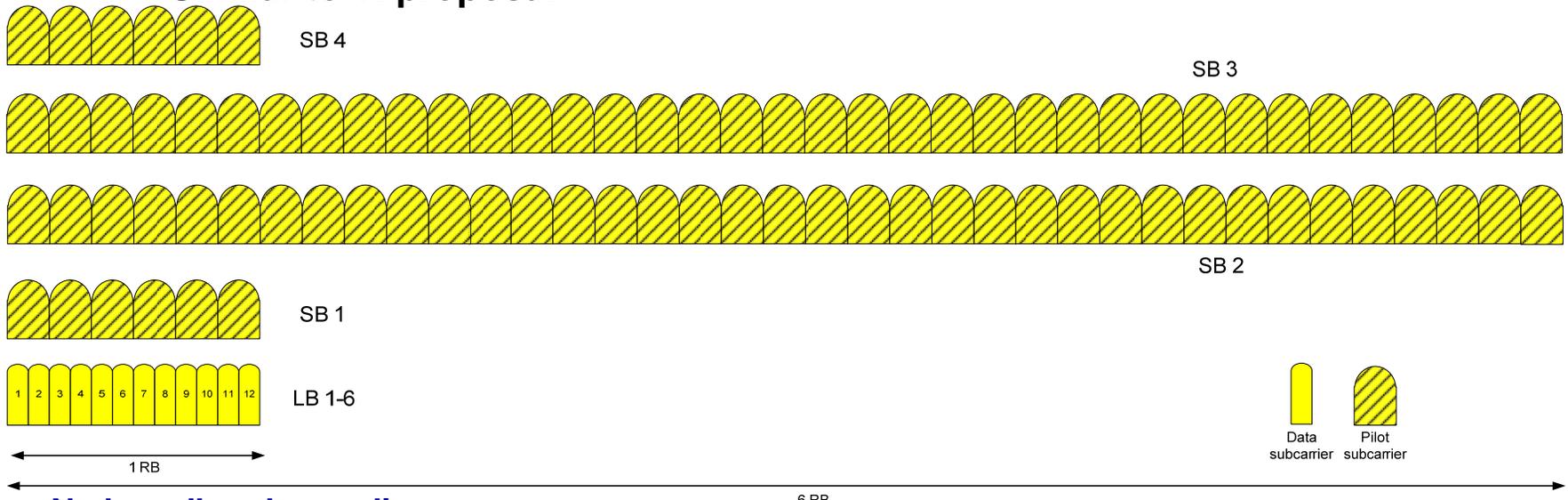
- Option 3: Half of SBs are localized FDM (like Option 1, Config. 1a), half are at least 1.25 MHz with RPF=2 (like Option 2)



- No advantage over Option 1 in terms of sequence reuse planning
- Potential issues
 - Degraded performance for high speed mobiles
 - Inability to encode demodulation RS cyclic shifts over the 2 localized FDM SBs (due to large time separation)
 - Degraded performance compared to Option 1 for UE with intra-TTI frequency hopping

Potential “Ways Forward” – Option 3b

- **Option 3b: Same as Option 3, but no FDM comb for sounding**
 - Similar to TI proposal



- **No broadband sounding**
- **No advantage over Option 1 in terms of sequence reuse planning**
- **No sounding bandwidth flexibility**
- **Other potential issues**
 - Degraded performance for high speed mobiles
 - Inability to encode demodulation RS cyclic shifts over the 2 localized FDM SBs (due to large time separation)
 - Degraded performance compared to Option 1 for UE with intra-TTI frequency hopping

Appendix: CDM Walsh Encoding Issues for Data Demodulation RS

- **If CDM used for data demodulation RS (to get longer sequence), there is a cost in delay spread/Doppler performance**
 - **Walsh coding over both SB assumed to provide adequate #users using one base sequence and a number of “shifts”**
 - Same set of cyclic shift values (multiple of D samples) used in both group of UEs (UE 1 to 3 in group 1 and UE 4 to 6 in group 2 on same RS)
 - No near-far problem if restrict to one base sequence
 - **Degradation at high delay spread**
 - A fraction of a dB when channel delay spread approaches shift length (~0.5dB for TU channel)
 - **Degradation at high Doppler**
 - Group 1 and group 2 interfere with each other (within a single SB) regardless of the delay spread – the interference cancellation relies completely on the collapsing (combining) of the pilots of both SB1 and SB2
- **Careful selection of the shift values may mitigate the degradation**
 - **Cyclic shift values for second group of users should be offset so that high Doppler only causes degradation when high delay spread is present**
 - By offsetting the cyclic shift values used by UEs in group 2 by $D/2$ relative to group 1, orthogonality *within* each SB can be achieved at moderate delay spreads, thus significantly enhancing the tracking of high Doppler channels