Australian Centre for Space Engineering Research (ACSER)

Distributed Beamforming Architectures for Space & Airborne Applications:

Taxonomy, Requirements & Synergies

Presented by

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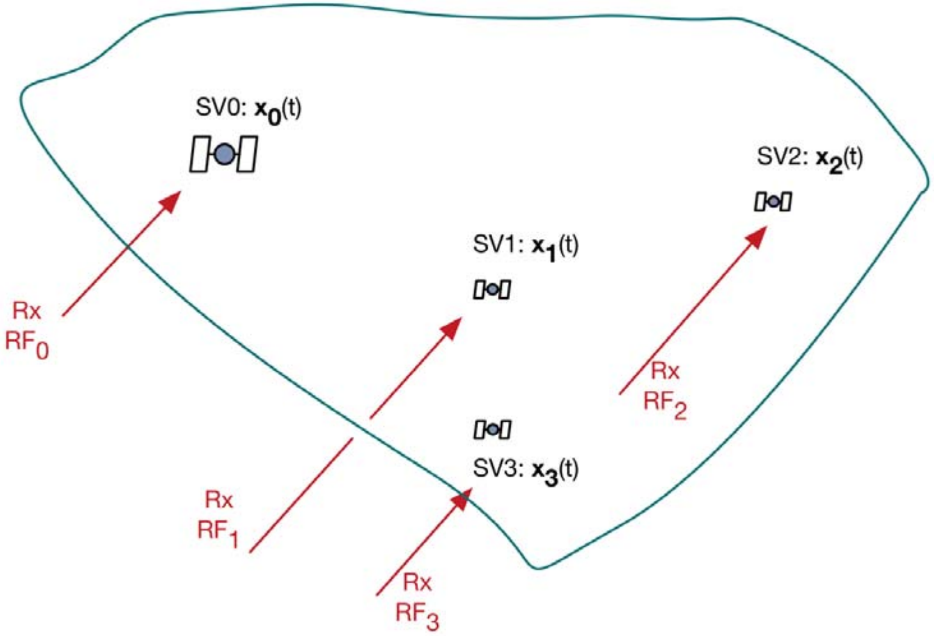
Airborne & Spaceborne Distributed Beamforming

- Many terms for the same concept:
  - collaborative beamforming, cooperative reception, virtual antenna arrays, distributed antenna arrays, synthesized antenna arrays, …
- Basic idea :
  - Use physically separated antennas to achieve improved sensitivity / resolution / interference rejection / et cetera compared with a single antenna
    BUT
  - the antennas are on unconnected mobile platforms
- Example :
  - Very Long Baseline Interferometry (VLBI) radio astronomy using airborne or spaceborne platforms with multiple receivers

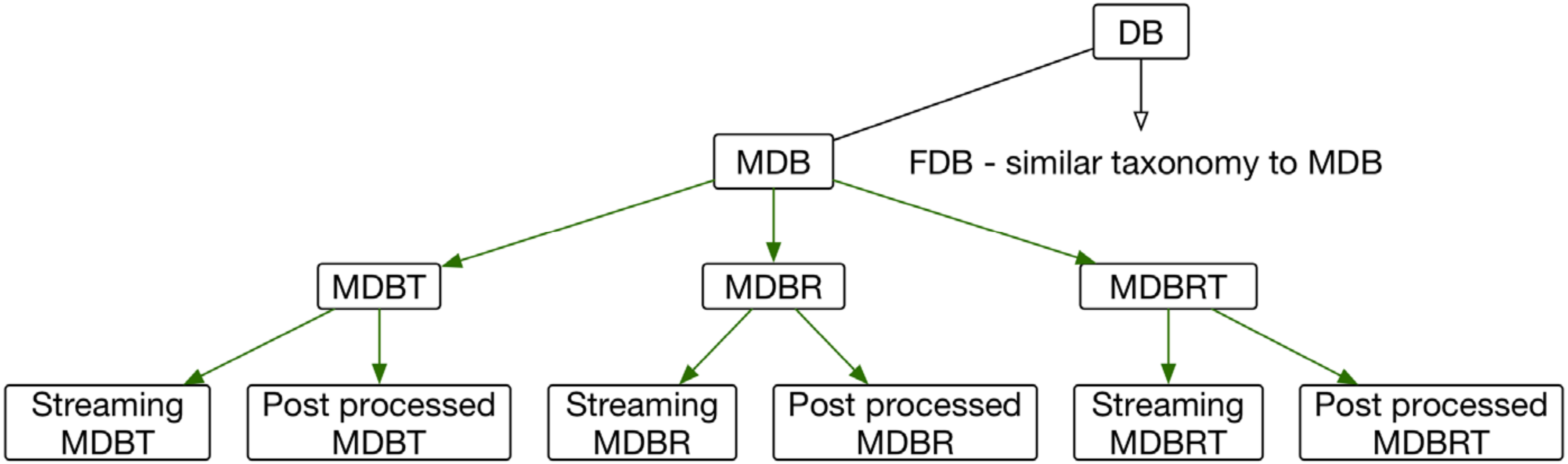
Spaceborne Distributed Beamformer

- Multiple receive/transmit antennas (SV0, SV1, SV2, SV3, …)
- Each with different trajectories and independent clocks
- Receive signals need to be combined or transmit signals steered
- Questions
  - What architectures are there?
  - What are the system level requirements? What are the sub-systems needed?
  - What are the difficulties? Why?



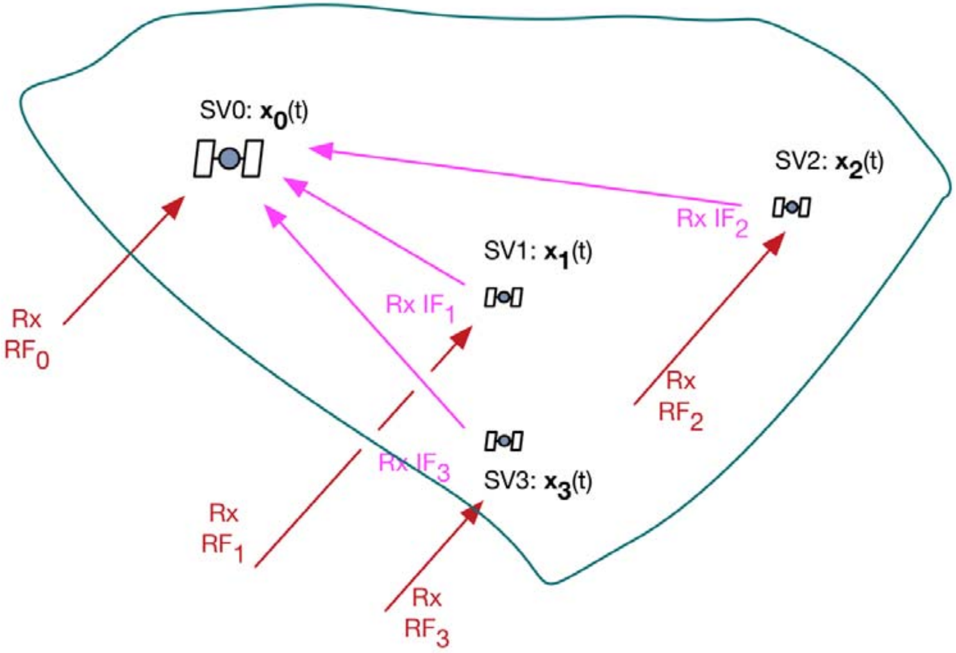
Architectures and Taxonomy

- Fixed or Mobile – only interested in Mobile here
- Receiver / Transmitter / Receiver-Transmitter (Transceiver)
- Streaming or Post-processing



MB Receiver Requirements 1 & 2

- Receive RF from target with multiple physically separated antenna
  - Receive antenna & radio
- Transmit downconverted RF (IF) to a reference receiver for processing
  - Transmit antenna & radio
- Streaming MBR illustrated – SV0 is the reference node performing the beamforming



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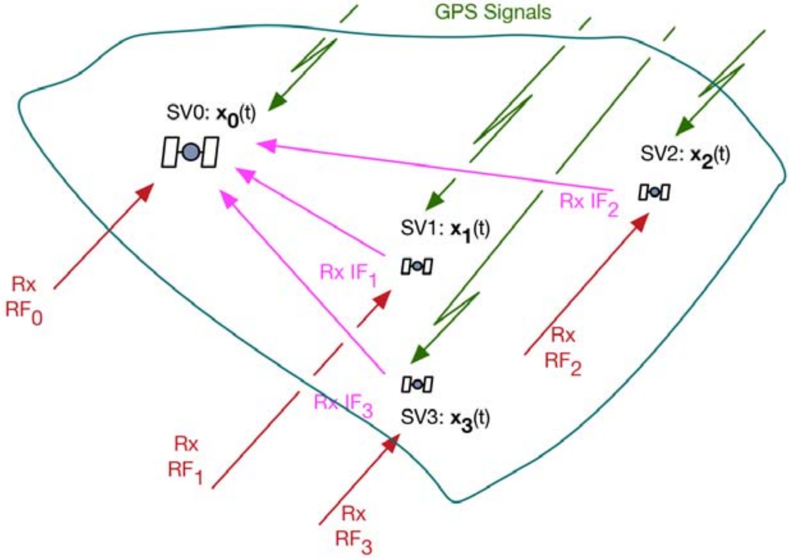
MB Receiver Requirements 3 & 4

- Be capable of determining the system geometry to within (say) 1/10 of a wavelength of the RF carrier
  - Relative navigation capability required
- Be capable of determining reference frequency clock bias/drift of the locally generated RF carrier to within (say) 1/10 of a wavelength
  - Synchronisation / syntonisation capability required
- The attitude of each node should be measurable to allow for lever-arm effects between the radio-navigation antennas and the beam-forming antennas



MB Receiver Requirements 5 & 6

- Reference receiver shall to use signals, geometry, timing information to perform required beamforming
- Geometry of the receiver network shall be controllable to achieve desired outcome

- MB Transmitter Requirements are similar, but differ in that each node is required to adjust the phase & frequency of its transmission so that beamforming can take place.
- MB Transmitters also suffer from the ‘thinned array curse’, which limits their use for delivering power

MB Receiver Requirement List

- Receive RF from target with multiple physically separated antenna
  - Receive antenna & radio
- Transmit downconverted IF to a reference receiver for processing
  - Transmit antenna & radio
- Be capable of determining the system geometry to within (say) 1/20 of a wavelength of the RF carrier
  - Relative navigation capability required, more difficult for higher frequency RF
- Be capable of determining reference frequency clock bias/drift of the locally generated RF carrier to within (say) 1/20 of a wavelength
  - Synchronisation / syntonisation capability required
- Reference receiver shall to use signals, geometry, timing information to perform required beamforming
- Geometry of the receiver network shall be controllable to achieve desired outcome

Tx / Nav / Synchronisation Synergies

- Mobile distributed beamformers required to operate in real time require high capacity communications between nodes
  - Needed to perform the weighted summations for beamforming
- Mobile distributed beamforming is difficult because the navigation and timing constraints are so demanding
  BUT
- The presence of the communications also provides the opportunity to perform some degree of synchronisation & syntonisation
  - Provided a COMS system capable of synchronisation/syntonisation is used, which is not true for most COTS chipsets
- Whether such an addition would allow GPS to be replaced depends on its performance
- Challenging to meeting these requirements even with real-time-kinematic (RTK) carrier phase GPS because RTK doesn't provide synchronisation

TerraSAR-X / TanDEM-X Example

- TerraSAR-X & Tandem-X are 1250 kg formation flying SAR satellites that fly within 300 m of each other
- Satellites use dual frequency RTK CPH GPS for navigation and a custom synchronisation system
- 3.84 m^2 phased array antenna at 9.8 GHz with 300 MHz bandwidth

Now consider substituting TanDEM-X with a BeamForming Cubsat constellation and assume that L or S band is being used instead of X band

- Multiple 6U cubesats (<12kg/SV) or 12 U cubesats (<24kg/SV)
- 2U Deployable antennas with a surface area of 1.7 m^2 at 3 GHz & gain of 30 dBi are available

Conclusions

- Plenty of scope for good research
- Very challenging due to the required:
  - Navigation precision
  - Timing (phase) synchronisation & (frequency) syntonisation precision
  - High capacity wireless communication between nodes
  - On-board processing to perform the required beamforming