

Spatial Multiplexing

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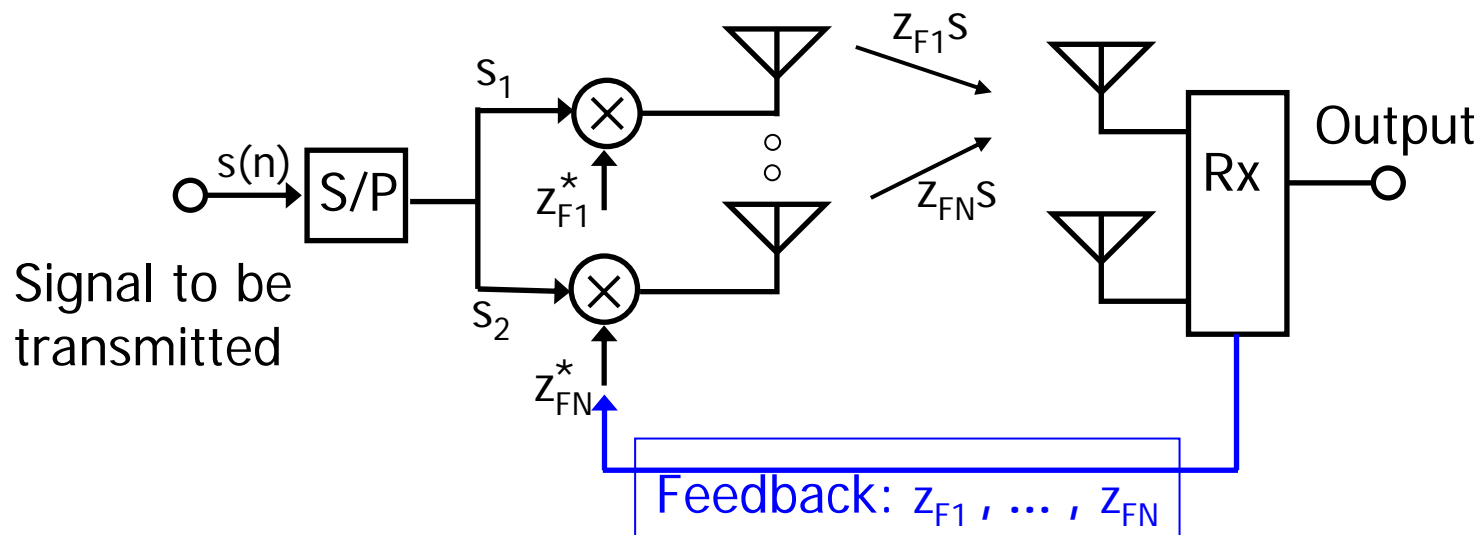
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1. Introduction to Spatial Multiplexing

- The basic concept of multiplexing: divide (multiplex) transmit a data stream several branches and transmit via several (independent) channels in
 - time \Rightarrow time–division multiplexing (TDM)
 - frequency \Rightarrow frequency–division multiplexing (FDM)
 - typical example: orthogonal FDM (OFDM)
 - space \Rightarrow space–division multiplexing (SDM) or *spatial multiplexing*
 - different bits from different antennae
 - requires independent channels
 - code \Rightarrow code–division multiplexing (CDM)
 - applied in 3G systems.

Spatial Multiplexing Idea

- Several different data bits are transmitted via several independent (spatial) channels.

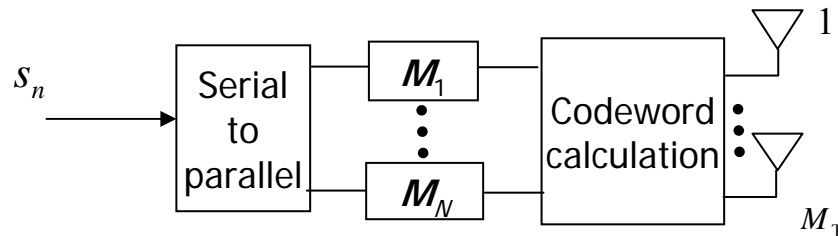


Characteristics

- No bandwidth expansion.
 - Space–time equalization needed in the receiver.
 - **Conventionally:** no. Rx antennae \geq no. Tx antennae.
 - The data streams can be separated by the equalizer, if fading processes of the spatial channels are (nearly) independent.
- ⇒ Actual **multiple–input multiple–output** channel with capacity linearly increasing the number of antennae or more precisely independent spatial channels.
- Alternative to spatial diversity: *multiplexing–diversity trade–off* is under intensive study.

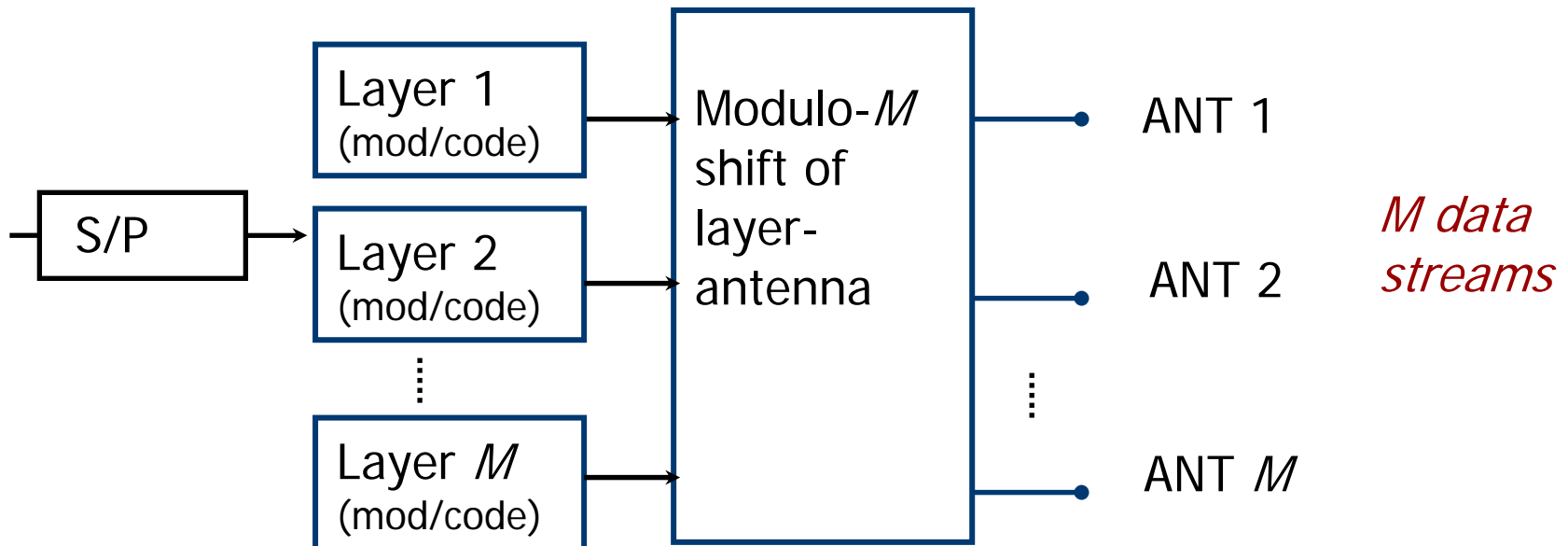
Linear Dispersion Coding

- Linear dispersion coding (LDC) offers a framework to combine spatial multiplexing and transmit diversity.
- Code design consists of finding optimum dispersion matrices.



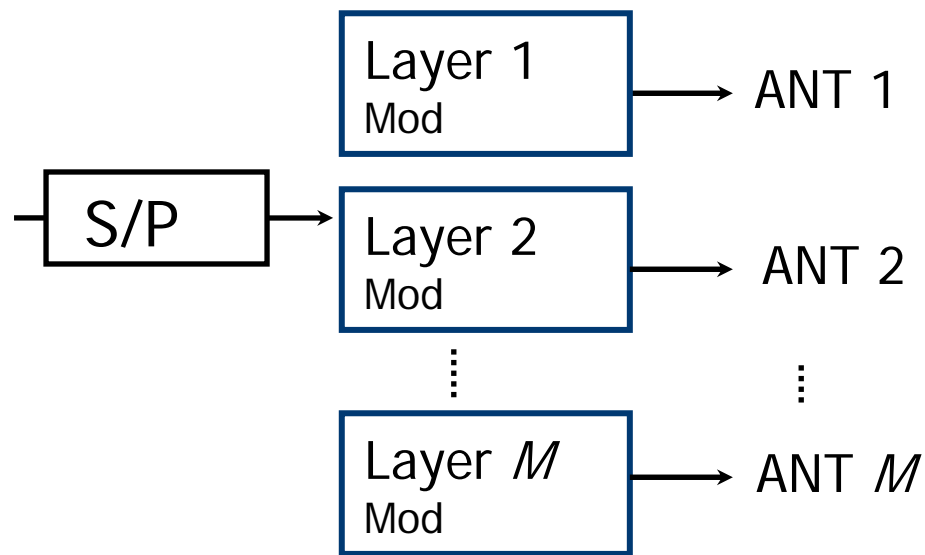
2. Layered Space–Time Architectures

- Bell Labs Layered Space–Time (BLAST) architecture was one of the first spatial multiplexing systems.
 - Called also layered space–time (LST).
- Detection originally based on linear and decision–feedback equalization, i.e., nulling and cancellation.



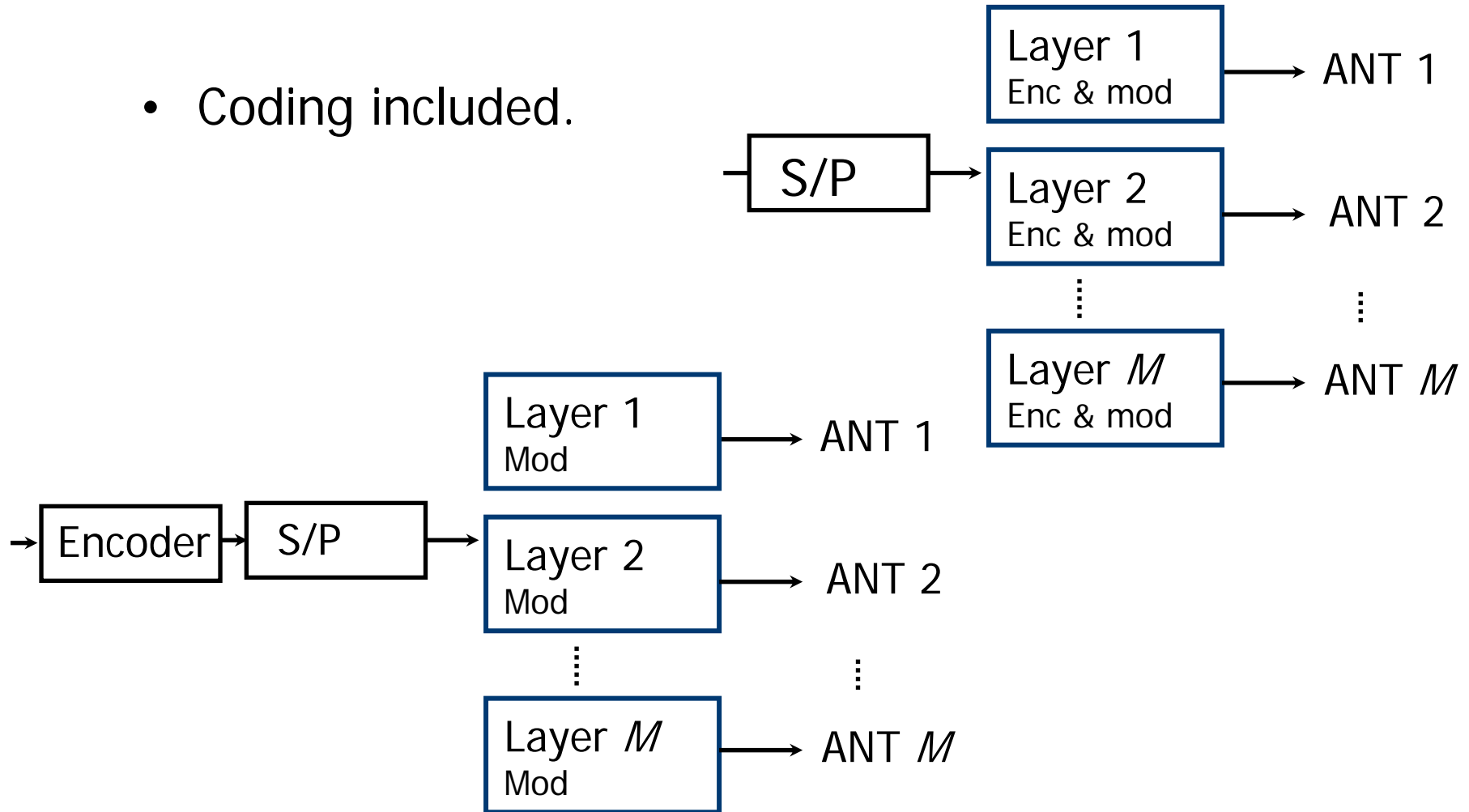
Vertical LST (V-LST)

- Basic scheme with no coding involved.



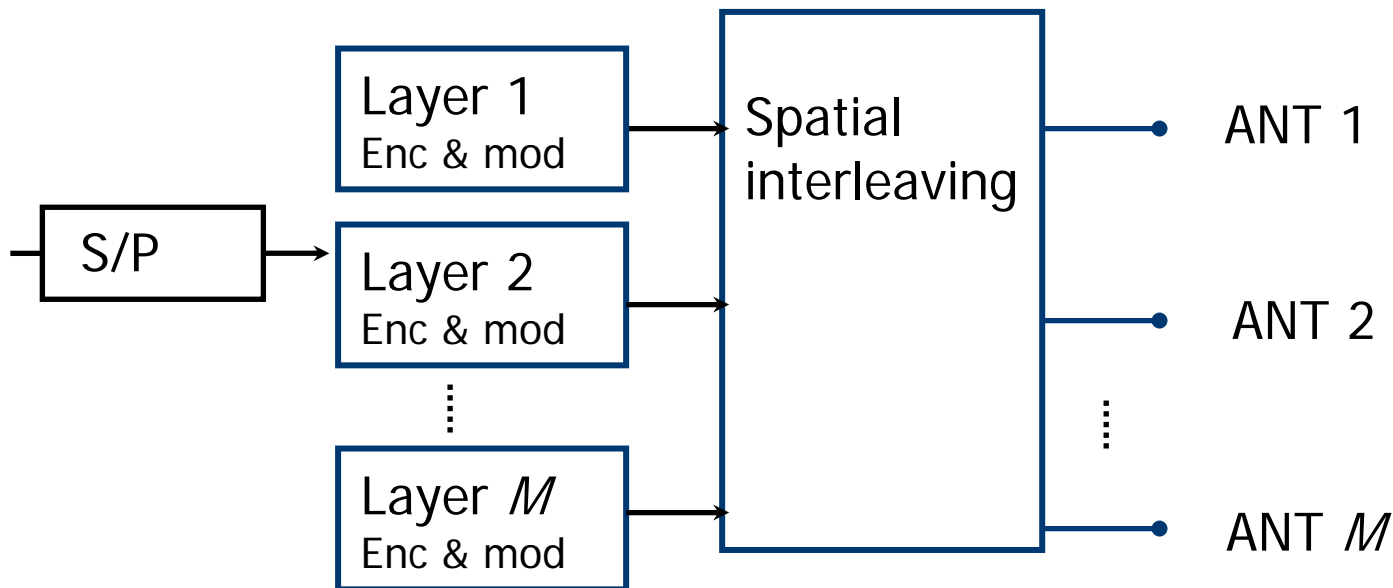
Horizontal LST (H-LST)

- Coding included.

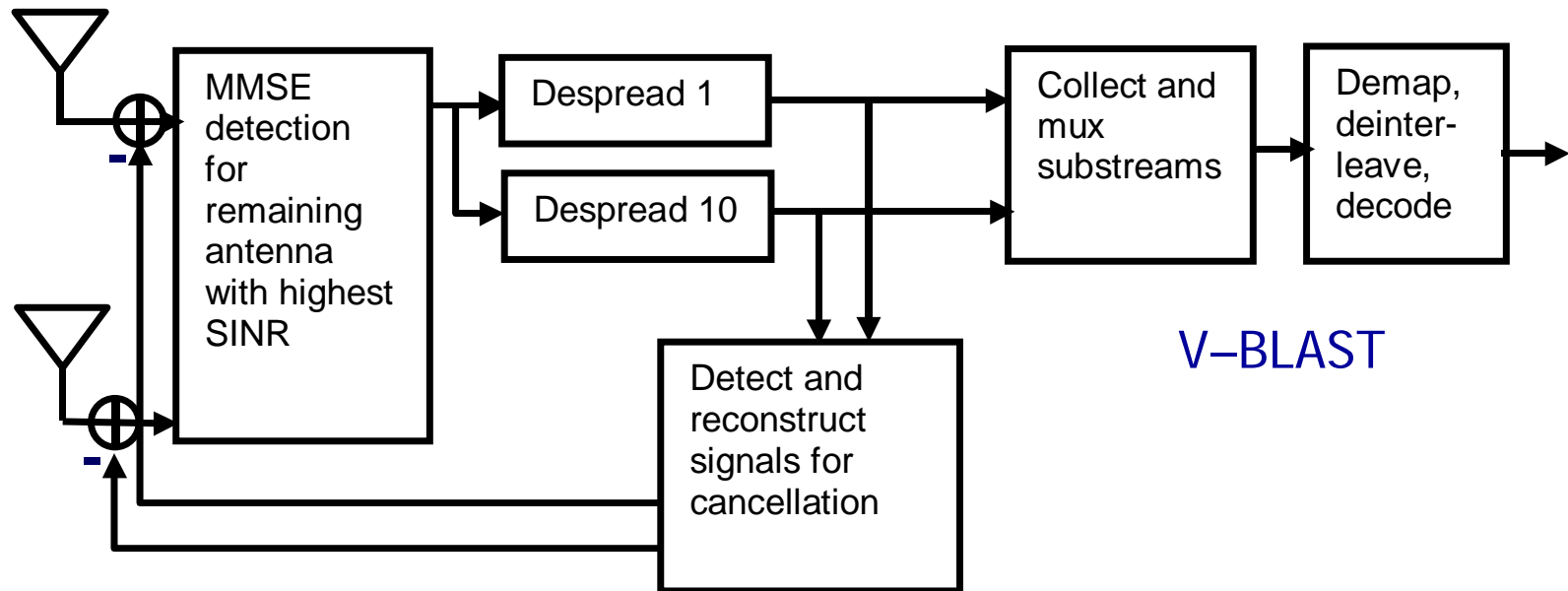


Diagonal LST (D-LST)

- Coding and spatial interleaving included.
- Spatial interleaving to improve performance via spatial diversity.

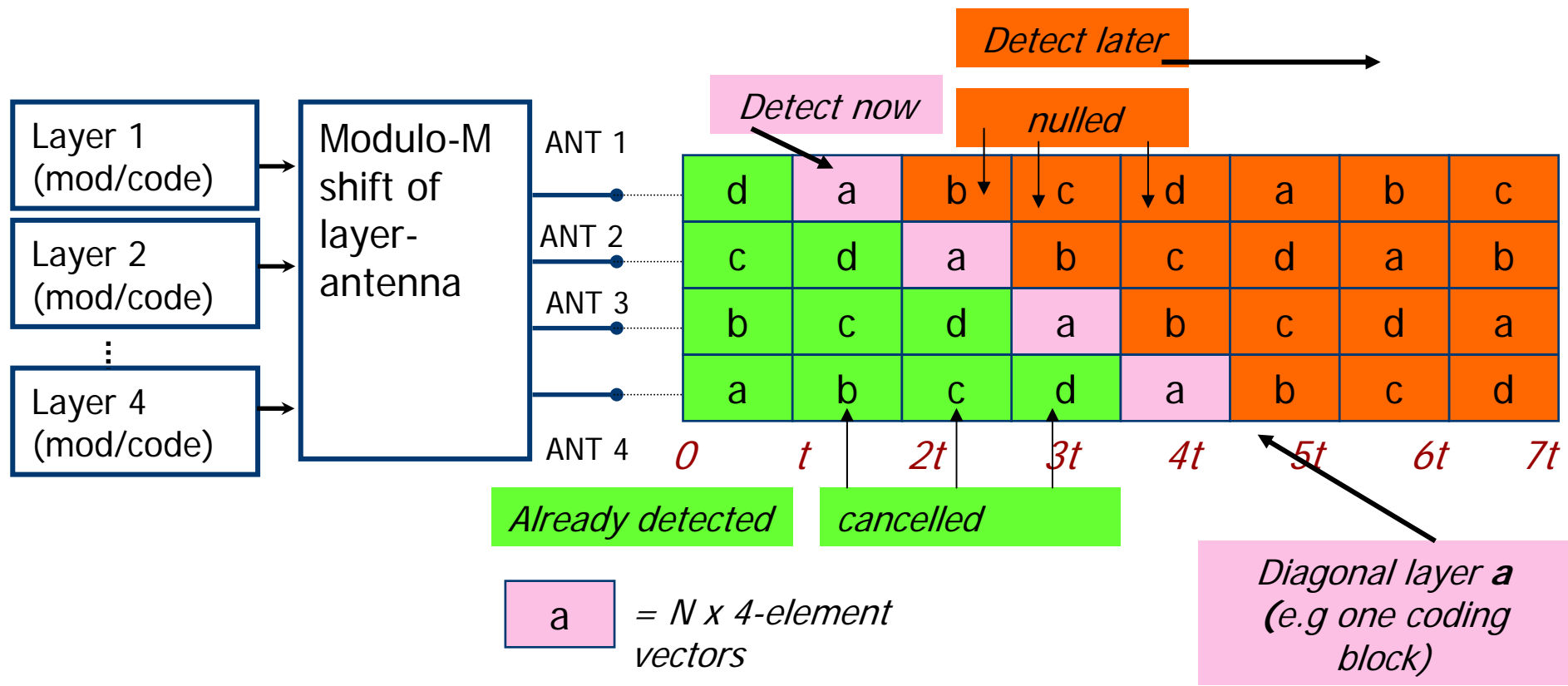


Nulling and Cancellation



V-BLAST

Nulling and Cancellation Order in D-LST



Space–Time Equalization

- The optimum receiver for LST transmissions is maximum a posteriori (MAP) equalizer similarly to the intersymbol interference (ISI) or multiple–access interference (MAI) channels.
- Suboptimal receivers include:
 - linear equalizers
 - interference cancellation (IC)
 - iterative (turbo) receivers
 - sphere detectors.
- Space–time equalization is under intensive study.

3. Spatial Multiplexing in 3G Systems: PARC

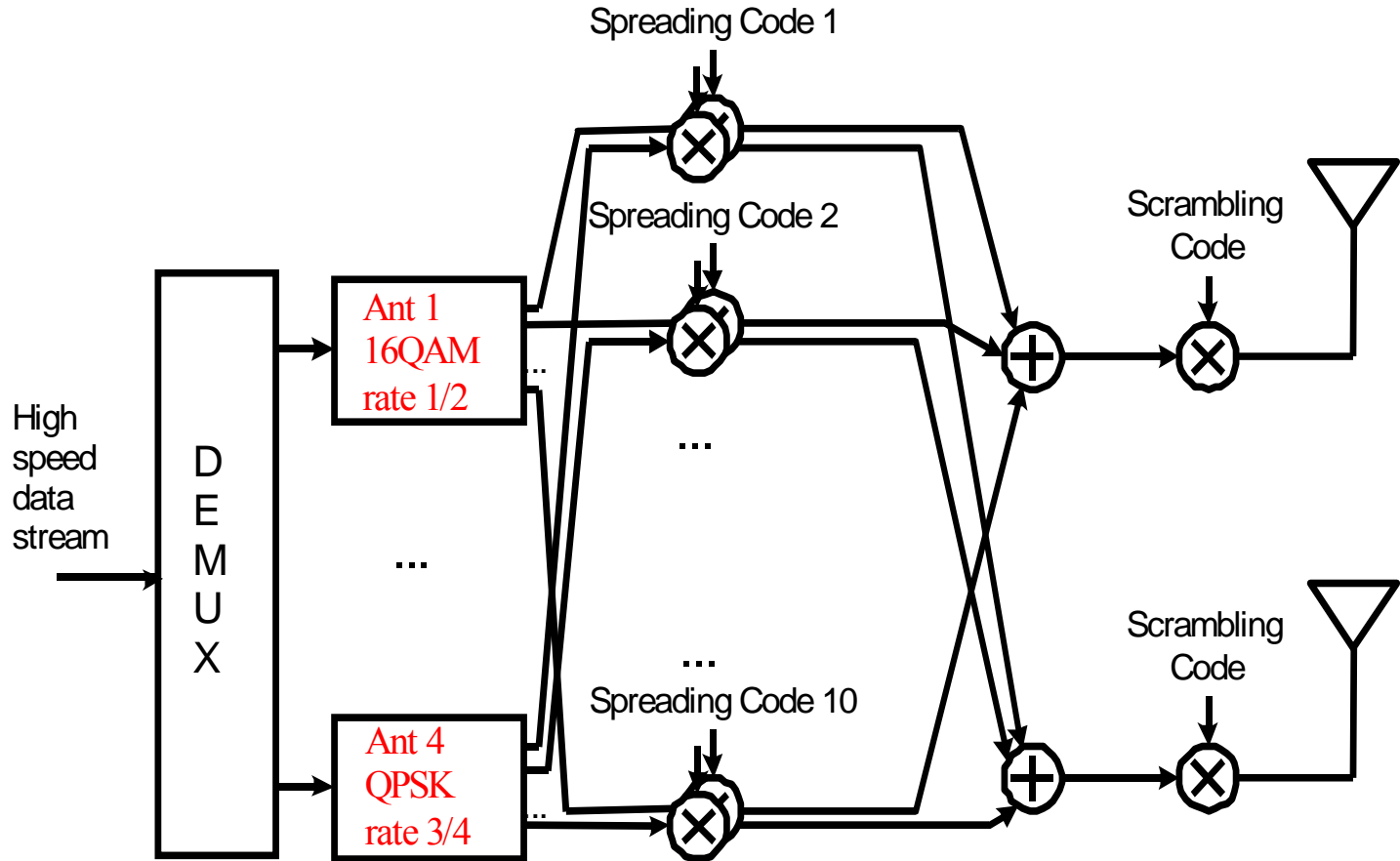
- Current MIMO proposals (e.g., code reuse, code reuse with STTD (DSTTD)):
 - Node B transmits with *the same rate on each antenna* (or antenna pair) depending on UE feedback and spatial channel realization

If the transmitter can adjust the antenna rates independently, a layered receiver architecture (MMSE with successive cancellation) can approach Shannon capacity. [Varanasi, Guess 1998] [Chung, Huang, Lozano 2001]

- **Per-antenna rate control (PARC)** for HSDPA MIMO:
 - Node B adjusts antenna rates independently depending on UE feedback and spatial channel realization.
 - Receiver consists of MMSE linear transformation followed by interference cancellation based on decoded bits.

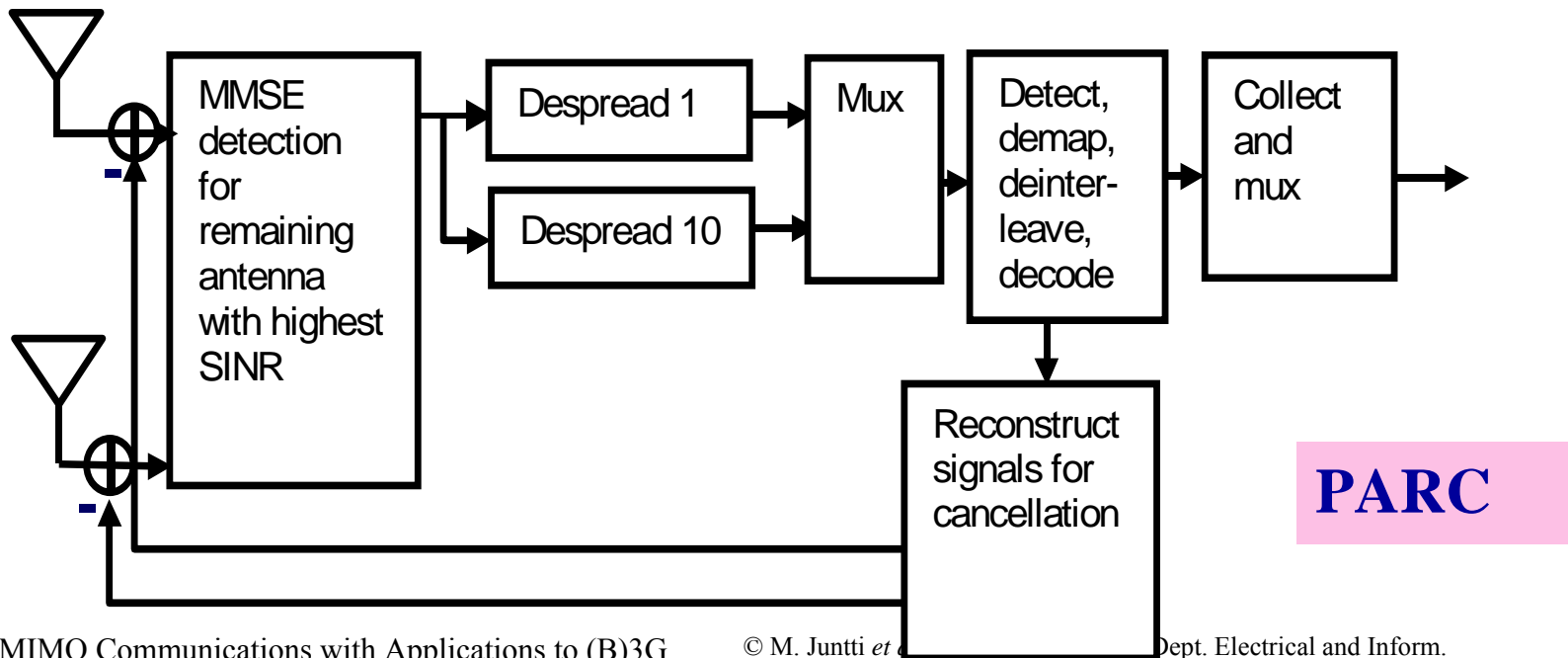
PARC: Transmission technique

- PARC MIMO transmission example:



PARC: Receiver technique

- Proposed MIMO receiver for PARC transmission
 - MMSE linear transformation followed by interference cancellation based on decoded bits.
 - Coding gain results in performance improvement over pre-decoding interference cancellation receiver.
 - This architecture can also be applied to conventional code reuse transmission.



PARC

4. Summary and Conclusions

- MIMO techniques allow high user data rates
- Advanced receivers have to be applied for MIMO systems
- Additional receiver diversity beneficial
- Feedback of CSI may lead to complex systems
- MIMO performance has to be evaluated at system level

References

1. G. J. Foschini, "Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas," *Bell Labs Tech. J.*, vol. 1, no. 2, pp. 41–59, 1996.
2. G. J. Foschini, G. D. Golden, R. A. Valenzuela, and P. W. Wolniansky, "Simplified processing for high spectral efficiency wireless communication employing multi-element arrays," *IEEE J. Select. Areas Commun.*, vol. 17, no. 11, pp. 1841–1852, Nov. 1999.
3. G. D. Golden, C. J. Foschini, R. A. Valenzuela, and P. W. Wolniansky, "Detection algorithm and initial laboratory results using V-BLAST space-time communication architecture," *Electronics Letters*, vol. 35, -no. 1, pp. 14–16, Jan. 1999.
4. B. M. Hochwald and S. ten Brink, "Achieving near-capacity on a multiple-antenna channel," *IEEE Trans. Commun.*, vol. 51, no. 3, pp. 389–399, Mar. 2003.
5. B. Vucetic & J. Yuan, *Space–Time Coding*. John Wiley and Sons, 2003. ISBN 0-470-84757-3
6. P. W. Wolniansky, G. J. Foschini, G. D. Golden, and R. A. Valenzuela, "V-BLAST: An architecture for realizing very high data rates over the rich-scattering wireless channel," in *International Symposium on Signals, Systems, and Electronics (ISSSE)*, 1998, pp. 295–300.
7. L. Zheng and D. N. C. Tse, "Diversity and multiplexing: A fundamental tradeoff in multiple-antenna channels," *IEEE Trans. Inform. Theory*, vol. 49, no. 5, pp. 1073–1096, May 2003.