Beyond 3G Challenges

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Outline

- What’s beyond 3G?
- Some physical layer challenges
- Frequency domain transmission/reception
- Coverage enhancement by relay networks
- Summary

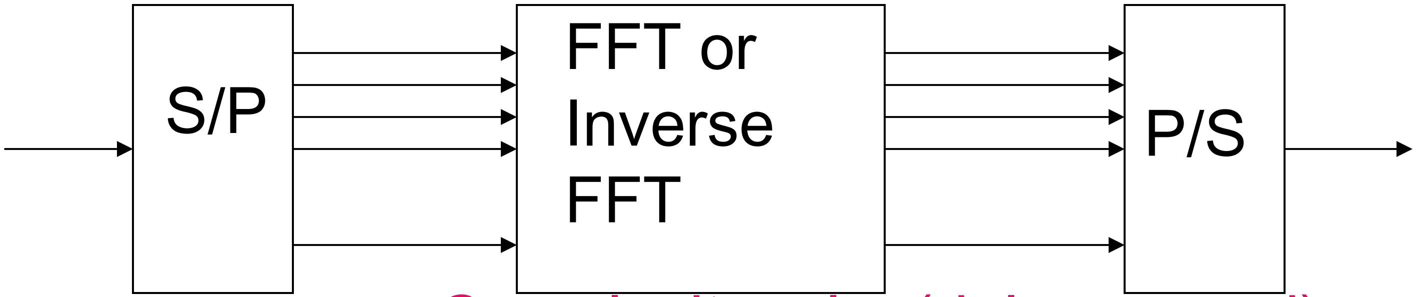
What is Beyond 3G?

...faster bigger smarter handier closer cheaper friendlier smoother easier quicker better….

- Starting point is user needs.
- IP-based, designed for data.
- Ubiquitous seamless service.
- > 10 times maximum speed of 3G, with about the same allocated spectrum.
- Also must accommodate high density of low-rate device-to-device terminals (100’s of b/s).
- Cheaper than 3G.
- Smarter systems, evolving capabilities, according to Moore’s law.

Physical Layer Challenges

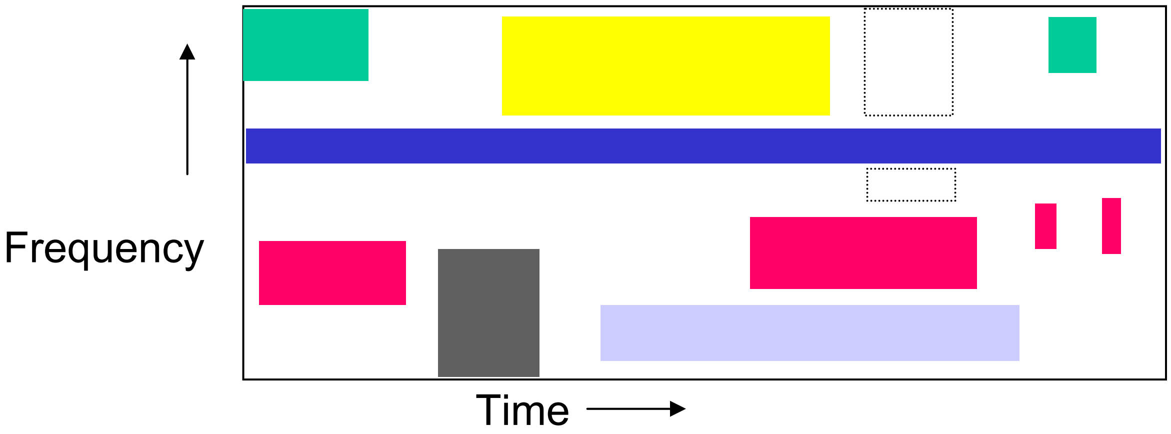
- Maximum aggregate bit rate up to 100 Mb/s, or even 1 Gb/s in non-line of sight frequency-selective radio propagation environments.
  - Calls for fast Fourier transform (FFT)-based block frequency domain transmission and reception.



Complexity ~ log(delay spread)

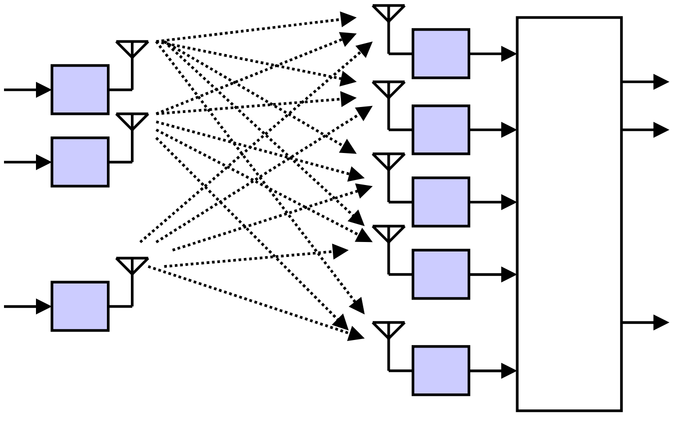
Physical Layer Challenges (Cont.)

- Good performance in harsh, diverse environments (Mobile, wide area, local area, licensed, unlicensed, multi-band,...)
  - Calls for robust interference suppression, dynamic spectrum-sharing, cognitive radio.



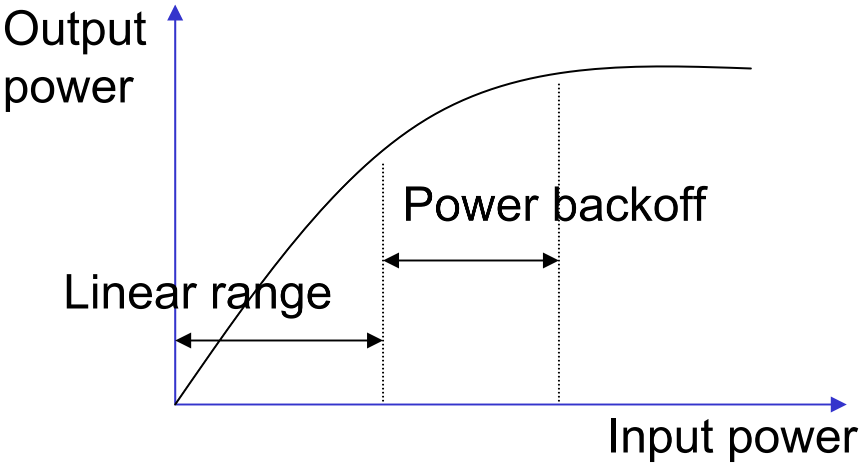
Physical Layer Challenges (Cont.)

- High spectral efficiency and capacity, making best possible use of limited spectrum
  - Calls for spatial (multi-antenna) processing; MIMO (multi-input multi-output) and SDMA (space division multiple access) techniques.



Physical Layer Challenges (Cont.)

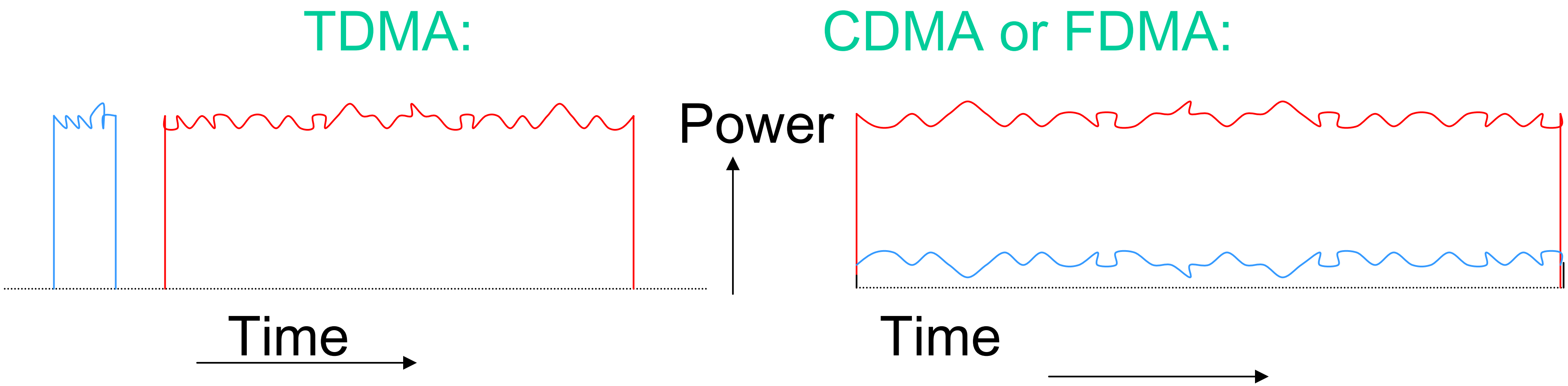
- All at low cost
  - Calls for low power, low cost RF, simplified digital signal processing.



Physical Layer Challenges (Cont.)

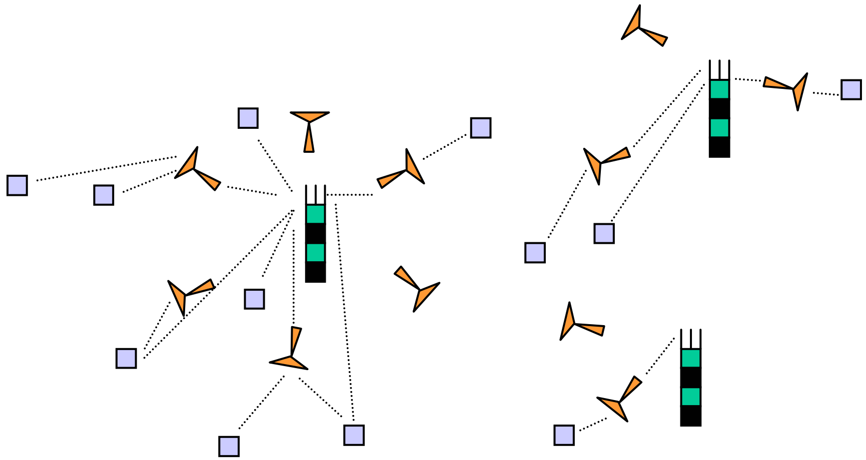
- Bit rate scalability: accommodating low bit rates at commensurate costs, as well as very high bit rates.
  - Calls for peak power proportional to bit rate; e.g. with CDMA or TDMA.

Blue represents low bit rate user's power, red represents high bit rate user's power



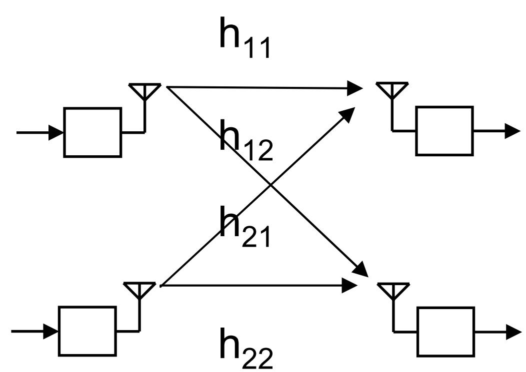
Physical Layer Challenges (Cont.)

- High coverage, low bit error rate.
  - Calls for adequate link budget using multihop architectures (relaying), powerful coding (e.g. turbo codes, LDPC), space-time codes, diversity, adaptive modulation and coding.



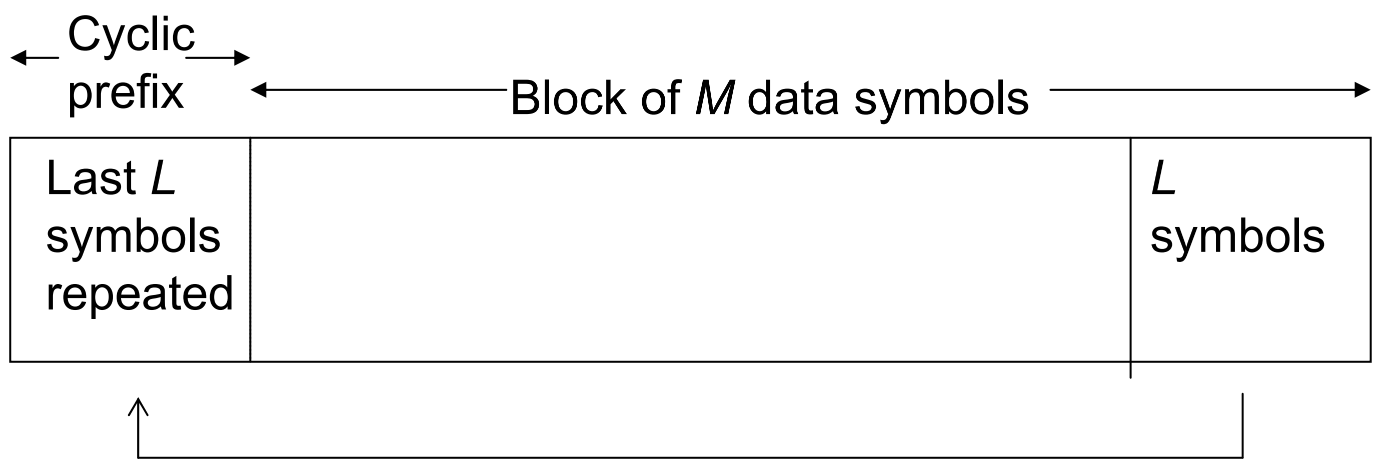
Physical Layer Challenges (Cont.)

- Accurate channel models.
  - Calls for high-bandwidth, multi-antenna measurement campaigns at appropriate frequencies.

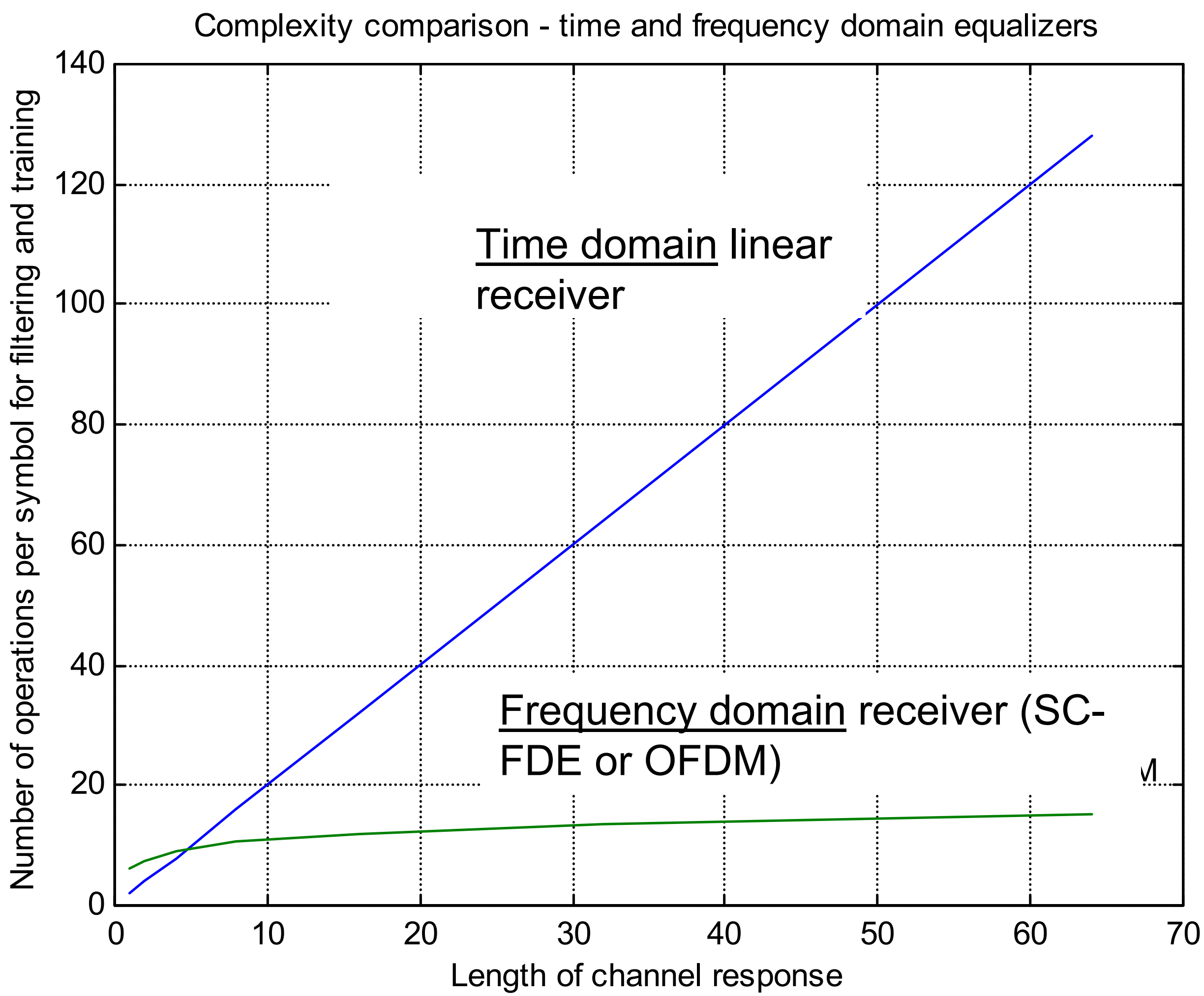


Block Processing in Frequency Domain Equalization

- Data symbols $\{a_n\}$ are transmitted in blocks of $(M+L)$ symbols, with a cyclic prefix of length $L >$ expected channel impulse response length.
- Receiver processes blocks of M symbol intervals in frequency domain by taking FFT (fast Fourier transform) of received block.
- Typically M is 5 to 10 times L.
- First and last L symbols may be training symbols.

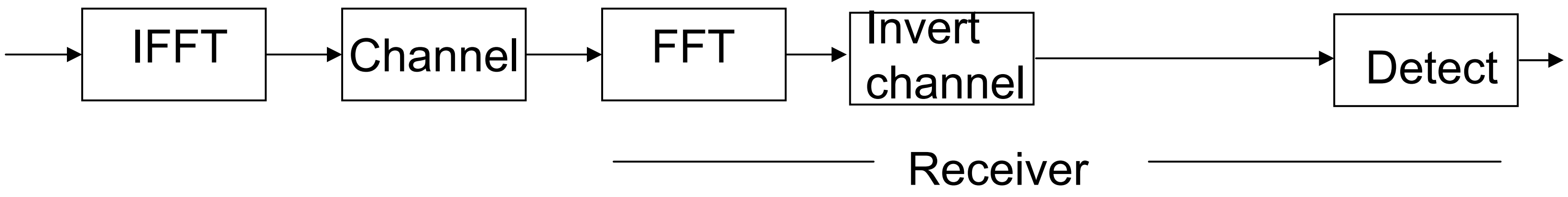


Complexity Comparison: Time- and Frequency-Domain Reception

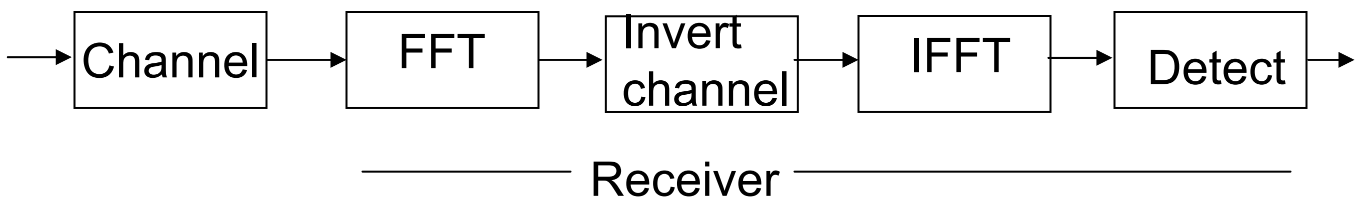


OFDM and Single Carrier with Frequency Domain Equalization (SC-FDE) – Signal Processing Similarities and Differences

OFDM :



SC-FDE:



FFT: fast Fourier transform
IFFT: inverse FFT

Comparisons

WHY USE OFDM?

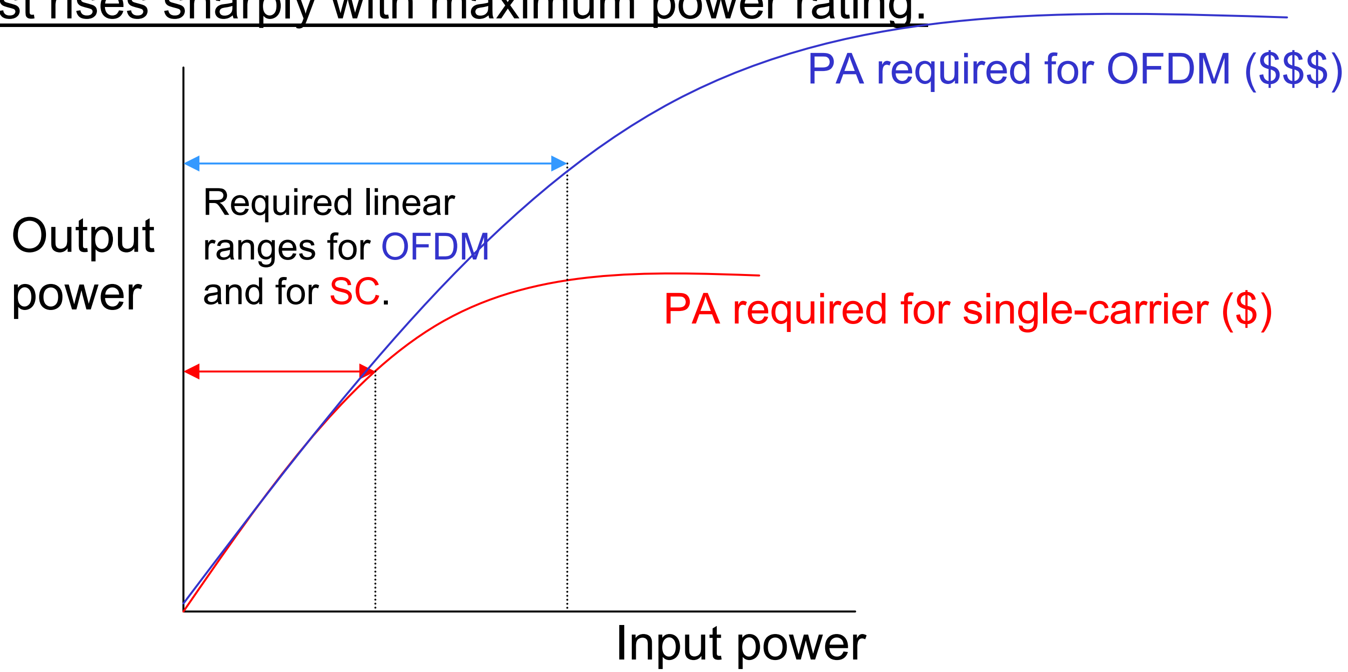
- With coding, good performance/ complexity tradeoff for high-delay spread channels.
- Compact spectrum due to simple frequency domain shaping.
- Flexible multiplexing and media access (frequency +time).
- Diversity obtained from interleaving and coding across frequency band.
- Spectral efficiency and performance can be enhanced by adaptive loading.

WHY USE SC-FDE?

- Good performance/complexity tradeoff for high-delay spread channels.
- Compact spectrum through low excess bandwidth pulse shaping.
- Simple efficient MAC (symbol-size packet granularity).
- Diversity obtained by equalization across the frequency band.
- Lower peak/avg. ratio $\rightarrow$ more efficient, cheaper power amplifier.

Power Amplifier Linearity Requirements and Cost

- Output power must be backed off from maximum rated PA power to keep spectral regrowth within regulatory mask.
- The greater the modulation scheme's peak to average ratio, the greater the required backoff, and the greater the required maximum rated power to achieve the link budget.
- PA cost rises sharply with maximum power rating.



OFDM in the Downlink, SC in the Uplink

- The subscriber transmitter is single carrier (SC), and thus is inherently more efficient in terms of power consumption, due to the reduced power back-off requirements of the single carrier mode. This will reduce the cost of a subscriber’s power amplifier.

- Most of the signal processing complexity is cost-effectively concentrated at the hub, or base station. The hub has two IFFT’s and one FFT, while the subscriber has just one FFT.

- OFDM in the downlink can exploit adaptive loading of subchannels for high efficiency and performance, and can multiplex users in both time and frequency.

Coverage Enhancement By Infrastructure-based Relay Network

- Low-cost digital or analog fixed relays
  - Located at strategic locations in cells

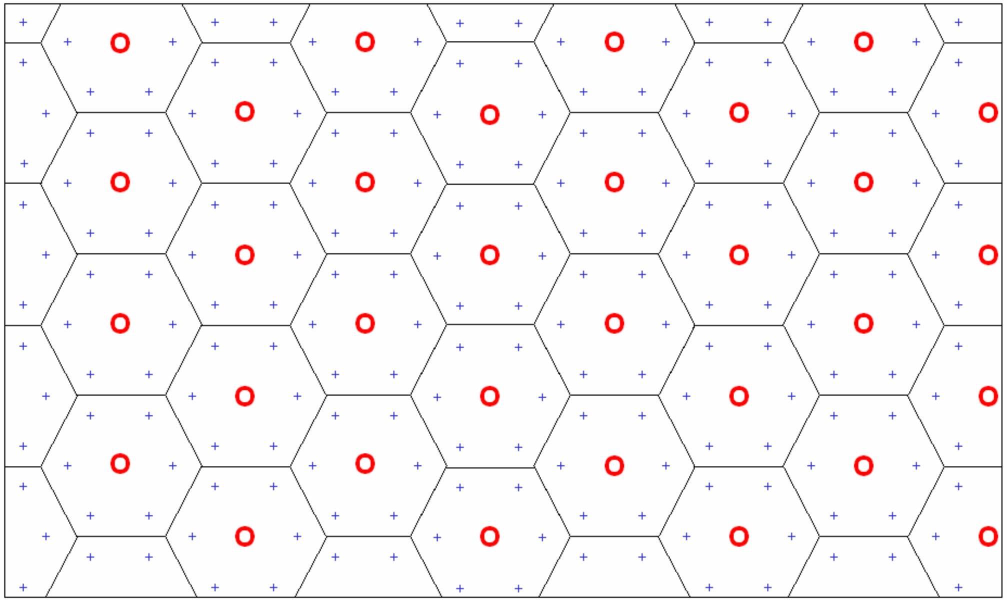
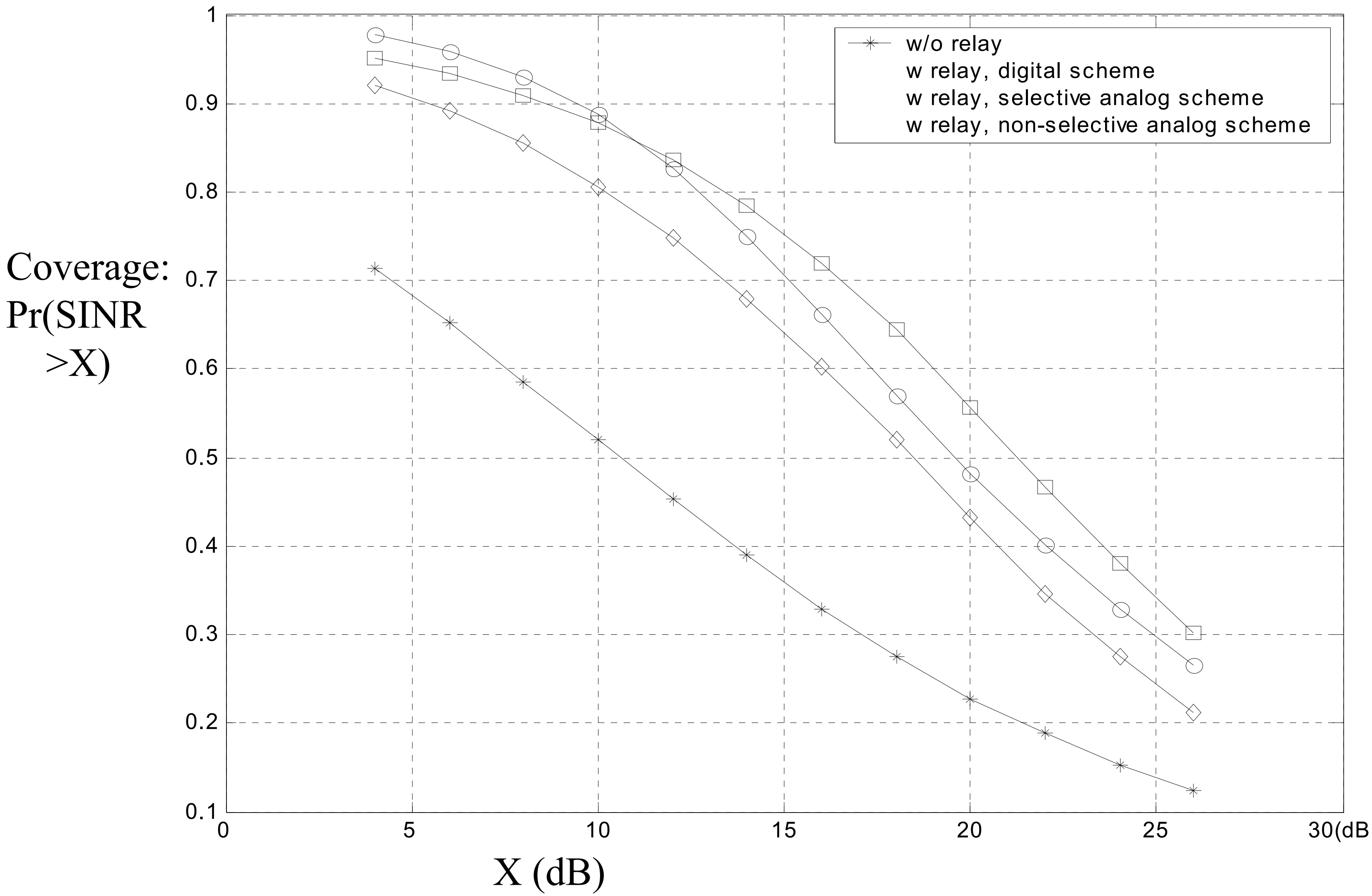


Illustration of Relaying Coverage Enhancement



Interference suppression factor=0.2; cell radius=500m.

Summary

- Key PHY layer techniques to meet B3G challenges:
  - Frequency domain transmission and/or reception- OFDM downlink, single carrier uplink.
  - Relaying/multihop
  - Cognitive radio
  - Smart antennas, MIMO, space-time coding, iterative coding and equalization.

EXTRA SLIDES

References

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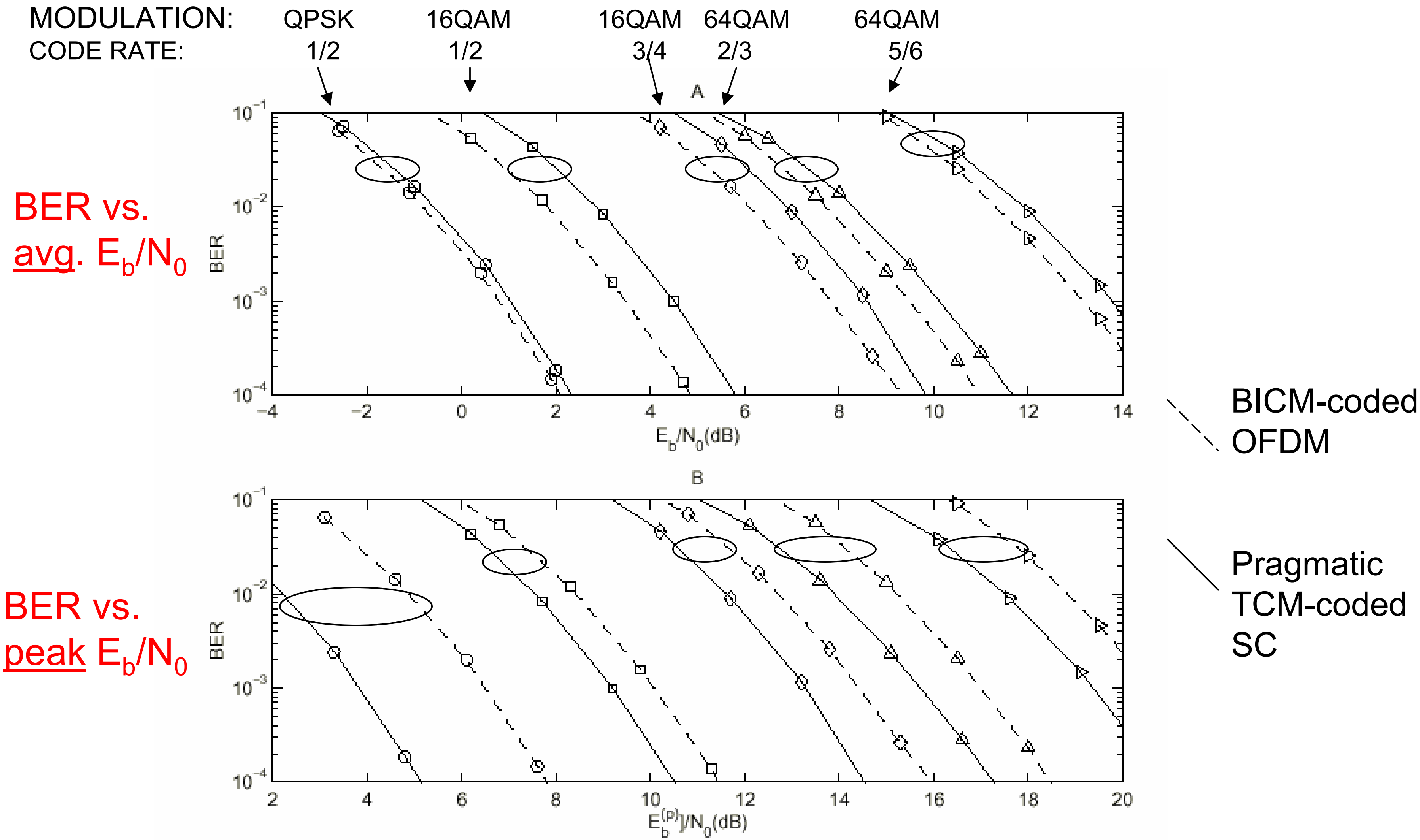
- D. Falconer, S.L. Ariyavisitakul, A. Benyamin-Seeyar and B. Eidson, “Frequency Domain Equalization for Single-Carrier Broadband Wireless Systems”, *IEEE Communications Magazine*, Vol. 40, No. 4, April 2002, pp. 58-66.
- D. Falconer and S.L. Ariyavisitakul, "Broadband Wireless Using Single Carrier and Frequency Domain Equalization", *Proc. 5th Int. Symposium on Wireless Personal Multimedia Communications,* Honolulu, Oct. 27-30, 2002.
- D. Falconer, R. Dinis, C.T. Lam and M. Sabbaghian, “Frequency Domain Orthogonal signature Sequences (FDOSS) for Uplink DS-CDMA”, *Proc. 10th WWRF Symposium*, New York, Oct. 2003.
- H. Yanikomeroglu and H. Hu, “Performance Analysis of Cellular radio Networks with Fixed Relays”, *Proc. 10th WWRF Symposium*, New York, Oct. 2003.
- W. Mohr, R. Lüder amd K-H. Möhrmann, "Data Rate Estimates, Range Calculations and Spectrum Demand for New Elements of Systems Beyond IMT-2000", *Proc. 5th Int. Symposium on Wireless Personal Multimedia Communications,* Honolulu, Oct. 27-30, 2002.
- H. Sari, G. Karam and I. Jeanclaude, “Frequency-Domain Equalization of Mobile Radio and Terrestrial Broadcast Channels”, *Proc. Globecom ’94*, San Francisco, Nov.-Dec. 1994, pp. 1-5.

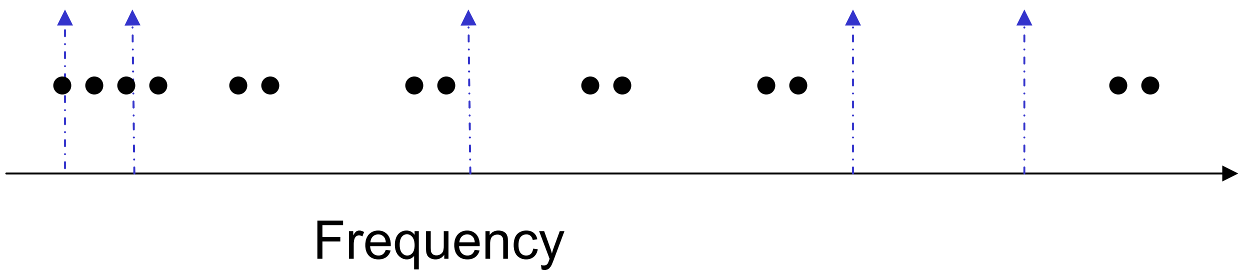
BER Comparisons on Fading Dispersive Channel



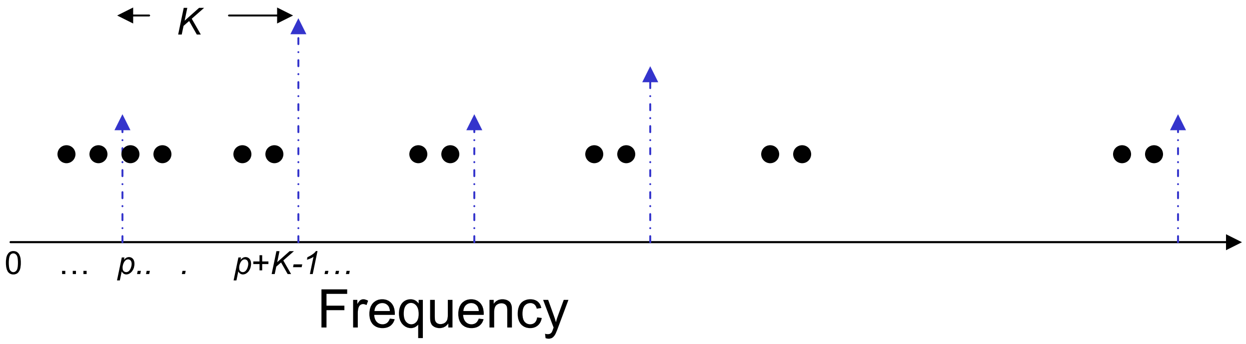
From: P. Montezuma and A. Gusmão, "A Pragmatic Coded Modulation Choice for Future Broadband Wireless Communications", Proc. VTC spring 2001.

Generating Signals in the Frequency Domain

(1) OFDMA: data symbols can occupy any set of frequencies, but signal has high peak/average power ratio.

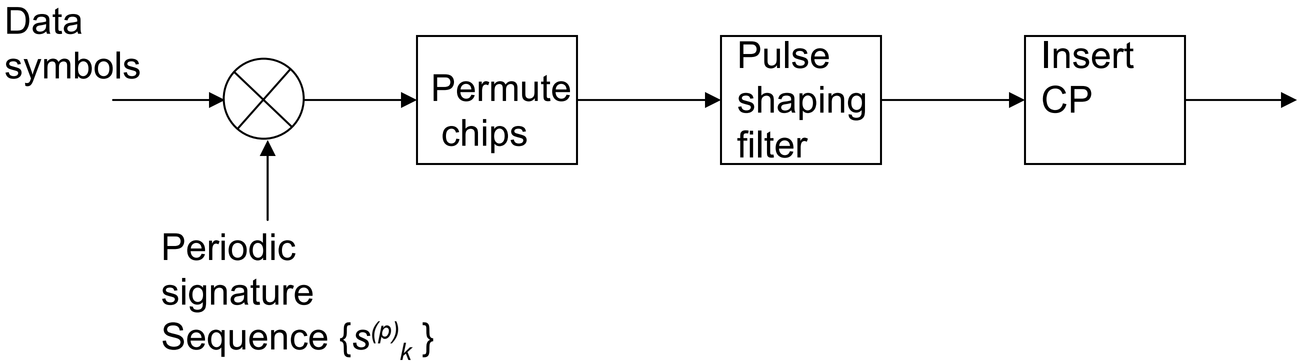


(2) FDOSS: FFT of data symbols occupy a set of equally-spaced frequencies; signal is equivalent to SC signal with low peak/avg.

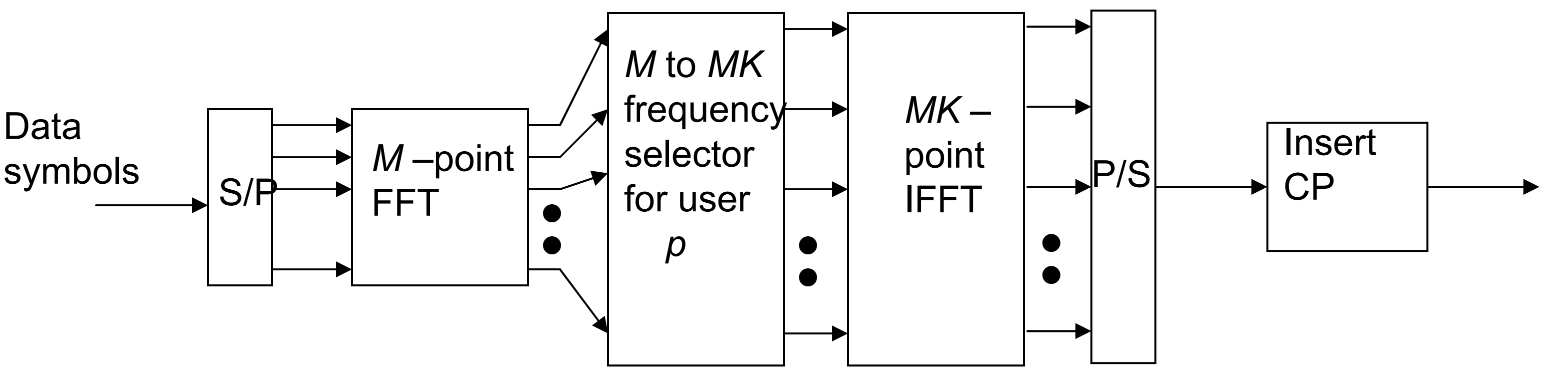


Two Equivalent FDOSS Transmitters

(1) Time Domain:



(2) Frequency Domain:



Frequency domain structure can be generalized [e.g. Wang and Giannakis, IEEE Sig. Proc. Mag., May, 2000]