Scheduling using Superposition Coding: Design and Software Radio Implementation

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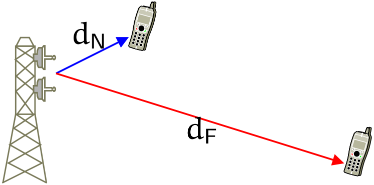
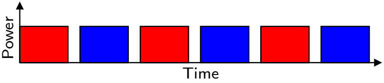
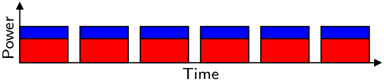
What is Superposition Coding?



A Wireless Broadcast Channel (Downlink)



Time Division Multiplexing



Superposition Coding

- 'Packetized' communication over a **Broadcast Channel** ↔ Base Station transmits to *two* users N (near) and F (far).
- Conventional strategies: establish orthogonal channels to the users, e.g., Frequency/**Time Division Multiplexing**.
- **Superposition Coding**: transmits a linear combination of the individually-coded user waveforms over a common interval/band.

Why Superposition Coding?

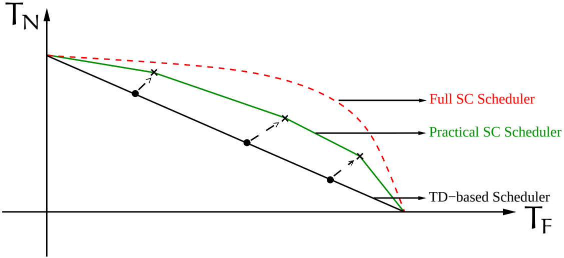
- N enjoys a higher signal-to-interference-and-noise ratio (SINR); thus, it can also decode the packets meant for F.
  - F decodes its packets in the presence of (little) interference from the near user's signal.
  - N performs *successive interference cancellation* before decoding its own packets.
- Superposition Coding (SC) and Successive Decoding (SD) achieves capacity in a scalar Gaussian broadcast channel !
  - The achievable rate pairs are strictly larger than that obtained by any orthogonal scheme, when the individual channel qualities are different [Tse and Viswanath '05].

Scheduling based on Superposition Coding

- A Time Division (TD)-based scheduler serves N and F in an orthogonal fashion.
  - N is **bandwidth-limited**, and benefits from an increased share of bandwidth.
  - F is **SINR-limited**, and benefits from an increased share of power.
- The SC-based scheduler judiciously reallocates transmit power and bandwidth to provide an improved performance.
  - Whenever F is to be served, the BS can superimpose N's packets onto F's packets.
  - N thus enjoys a higher bandwidth; its share of transmit power can then be reduced and vested in the transmissions for F.

$\Longrightarrow$ **Each user gets what he wants !**

The Big Picture



For each throughput pair obtained by the TD-based scheduler, we aim to achieve a higher throughput pair via reallocation of resources.

	Complexity	Decoding Delay	Optimal?
Full SC	High (Gaussian signalling)	Large (Long blocklength)	**Yes**
Practical SC	Low (Finite constellation)	Design-dependent (Adjustable)	**No**

Prior work

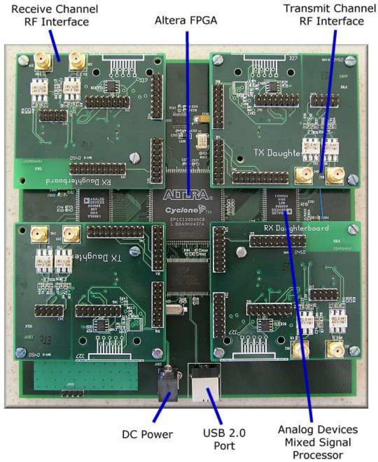
- SC-based greedy scheduler (simulation only) [Li et al. '07].
- Implementation of successive decoding [Gollakota et al. '09].
- PHY implementation of an OFDM-based SC system on the GNURadio/USRP platform [Ganti et al. '10].

Our Contributions

1. Design an intelligent scheduler based on SC and SD that outperforms orthogonal schemes.
2. Implement and verify the scheduler performance experimentally on a software-defined radio platform.

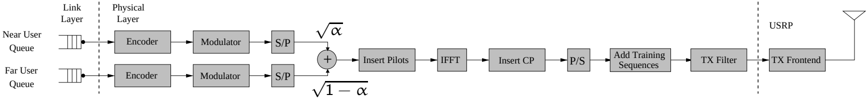
Implementation for Real-Time Processing

Close-up of USRP board



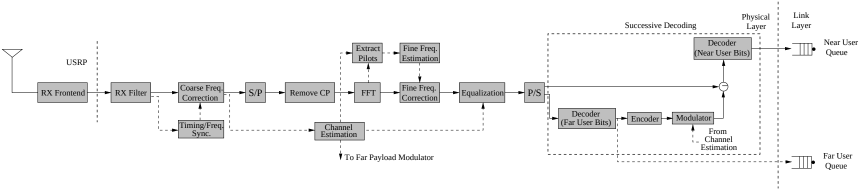
- Hardware: USRP 1 (Analog and RF front-end)
  - Programmable Channelization
  - USB 2.0 Interface
- Software: GNU Radio (ver. 10923) & its built-in libraries
  - Open-Source
  - Real-time Signal Processing on a GPP

Tx and Rx Block Diagrams



Block diagram of the transmitter.

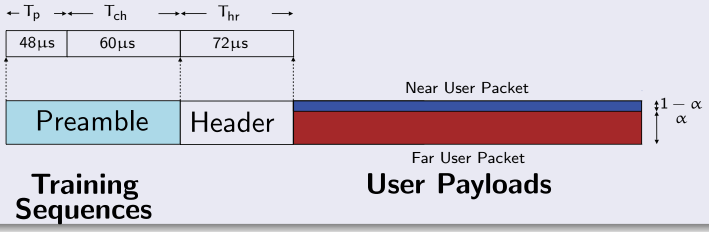
Powers allocated to N and F are α and $1-\alpha$ respectively.



Block diagram of the receiver.

The near user employs successive decoding to decode its payload bits.

Frame structure



System parameters

Center Frequency	903 MHz
System Bandwidth	1 MHz
Transmission Scheme	16-tone OFDM
Tones	8 data, 4 pilot, 4 null
CP Length	4µs
Gen. Poly. for Conv. Code	$[133, 171]$

A Design Example

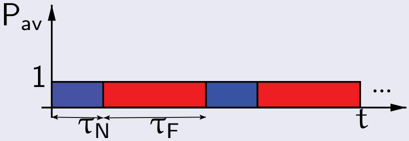
The TD-based Scheduler

Notation:

- u denotes the fraction of transmissions reserved for each user.
- ℓ denotes the packet size
- ρ denotes the the data rate.

The packet transmission time is $\tau = \ell/\rho$.
The fraction of times spent for transmissions to the user are

$$\begin{aligned} w_N &= \frac{u_N \tau_N}{u_N \tau_N + u_F \tau_F} \\ w_F &= 1 - w_N \end{aligned}$$

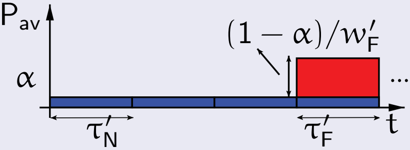


A Design Example (Contd.)

The SC-based Scheduler

- Lower N's rate to $\rho'_N = w_N \rho_N$, while $\rho'_F = \rho_F$.
- Modify the packet lengths such that the packets can be "completely" overlapped, i.e., set $\tau'_N = \tau'_F$.
- Choose a suitable value of $\alpha < 1$ such that N's reliability improves; F's transmissions are performed at higher power.

$$
\begin{aligned}
w'_N &= \frac{u_N}{u_N + u_F} \\
w'_F &= 1 - w'_N
\end{aligned}
$$



Consider the operating point $u_N = 3/4$.

TD-based Scheduler

- N: 300 bytes; 16QAM, rate 3/4; $\rho_N = 1.2$ Mbps.
- F: 300 bytes; BPSK, rate 1/2; $\rho_F = 0.2$ Mbps.

SC-based Scheduler

- $w_N = 1/3$: N's rate is lowered to 0.4 Mbps (QPSK, rate 1/2).
- Packets can be "overlapped": $\ell_F = 150$ bytes.
- Ratio of received power to noise variance at N is

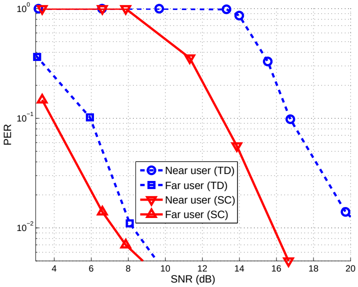
$$\frac{P_{\text{16-QAM, rate 3/4}}}{P_{\text{QPSK, rate 1/2}}} = \frac{(E_b/N_0)_{\text{16-QAM, rate 3/4}}}{(E_b/N_0)_{\text{QPSK, rate 1/2}}} \frac{1.2\text{Mbps}}{0.4\text{Mbps}}.$$

- $P_{\text{16-QAM, rate 3/4}} > 3 \times P_{\text{QPSK, rate 1/2}}$ or $\alpha < 1/3$.
- F's power is boosted by 167 % !

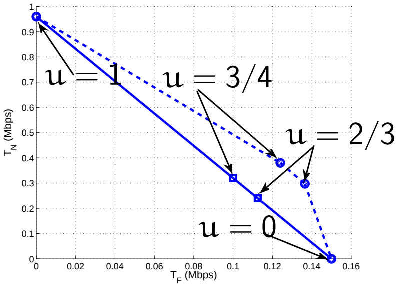
Scheduler parameters

Operating point	$u_N = 1$	$u_N = 3/4$	$u_N = 2/3$	$u_N = 0$
Near user's packet length	300 bytes	300 bytes	300 bytes	
Far user's packet length		150 bytes	200 bytes	300 bytes
Near user's modulation/coding	16-QAM, rate 3/4	QPSK, rate 1/2	BPSK, rate 3/4	
Far user's modulation/coding		BPSK, rate 1/2	BPSK, rate 1/2	BPSK, rate 1/2
Near Tx power	1	< 0.33	< 0.25	0
Far Tx power	0	> 2.67	> 2.25	1

Experimental Results



PER vs User SNR ($u_N = 2/3$)



Throughput region
($\mathrm{SNR_N} = 16$ dB, $\mathrm{SNR_F} = 4$ dB)

SC-based scheduler results in

- Lower PERs for both N and F.
- A larger throughput region ($T_i = w_i \rho_i (1 - \mathrm{PER}_i)$).

Conclusions and Future Work

Conclusions

- Realized superposition coding on a software-defined radio.
- Designed and implemented an SC-based scheduler.
- Obtained throughput gains of up to 25% over orthogonal schemes.

Future Work

- SC benefits under different data traffic models.
- Trade-off between reliability and delay for far user.
- Peak-to-average power ratio in transmission.