Wireless Networks In-the-Loop: Software Radio as the Enabler

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Overview

- Introduction: Network Simulators and Software Radio
- Design Concepts
- Implementation
- Sample Network
- Conclusion and Future Work

Overview

Wireless Networks In-the-Loop: Software Radio as the Enabler

Introduction: Network Simulators and Software Radio

Design Concepts

Implementation

Sample Network

Conclusion and Future Work

Introduction

Software Radio techniques allow for loop-testing of heterogeneous networks.

Design of wireless networks

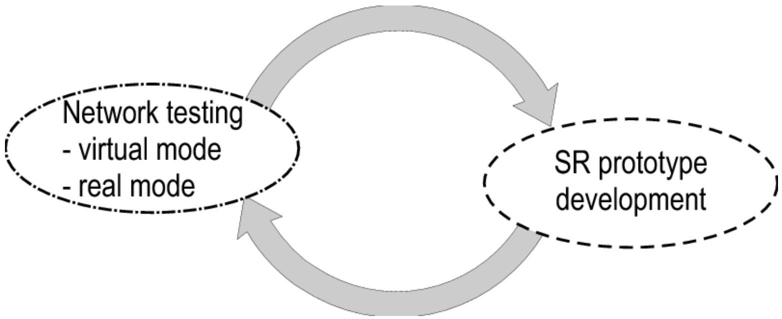
- Design requires theoretical analysis and computer-based Monte Carlo method simulations
- Simulation is done in parallel to design
- Dedicated tool: network simulators

Software Radio Techniques

- Iterative model-based design stages, e.g.,
  - Platform independent model
  - Platform specific model
  - Executable

Wireless Network In-the-Loop

- Simple idea: Use Software Radio code / model in simulation
- Offer virtual mode / real mode
- Use production code in simulation, reproducible test environment and results



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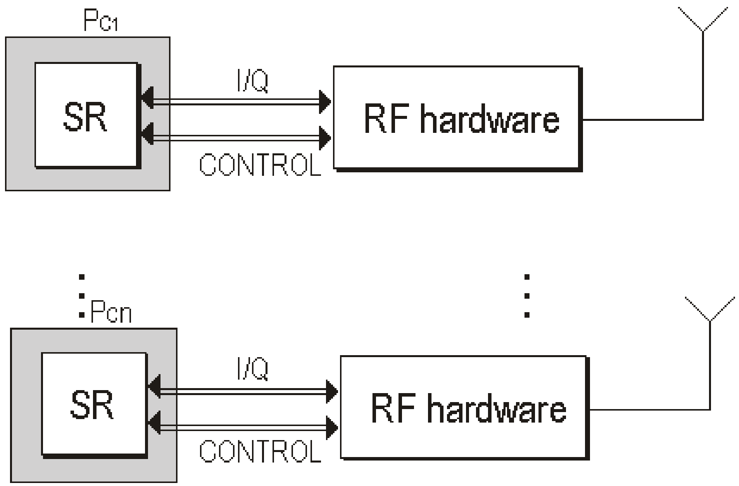
Design Concepts: Real Mode

Real mode needs standardized digital I/Q base band / RF software interface.

Real mode

- **Network in real environment:**
  - Different SR terminals running on different machines with different RF hardware
- **Components:**
  - SR terminal
  - RF hardware
  - Physical channel
- **RF hardware is addressed using a standardized software I/Q base band interface**
  - E.g. SDR Forum Transceiver Facility API or GNU Radio USRP API

System overview



See GNU Radio (http://gnuradio.org/trac) or E. Nicollet and L. Pucker, "Standardizing Transceiver APIs for Software Defined and Cognitive Radio," *RF Design*, Feb 2008, SDR Transceiver Facility Working Group

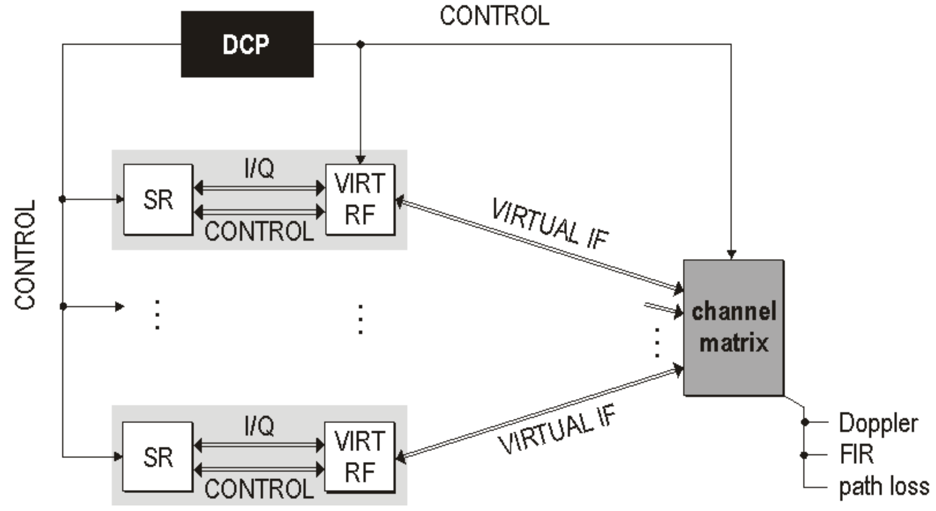
Design Concepts: Virtual Mode

Virtual mode additionally needs to abstract RF hardware and channel.

Virtual mode

- **Network in simulation:**
  - Components are run as separate processes, on same or separate machines
- **Components:**
  - **Dispatch / Control process**
  - **SR terminals**
  - **Virtual RF hardware**
  - **Channel matrix**
- **Virtual RF software API identical to RF software API**

System overview

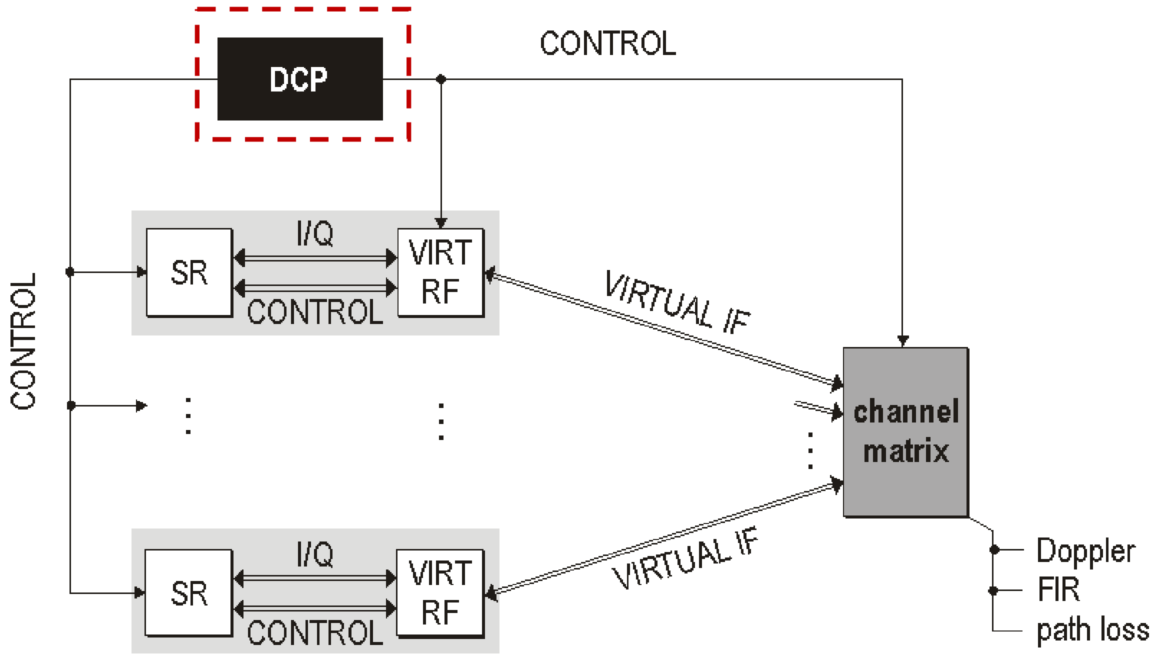


Design Concepts: Components Virtual Mode

DCP controls SR processes, provides world model and parameterizes channel matrix.

Dispatch and Control Process (DCP)

- **Initiates and controls the SR processes**
- **Responsible for selecting a channel model**
- **Constantly updates channel matrix process according to internal world model**

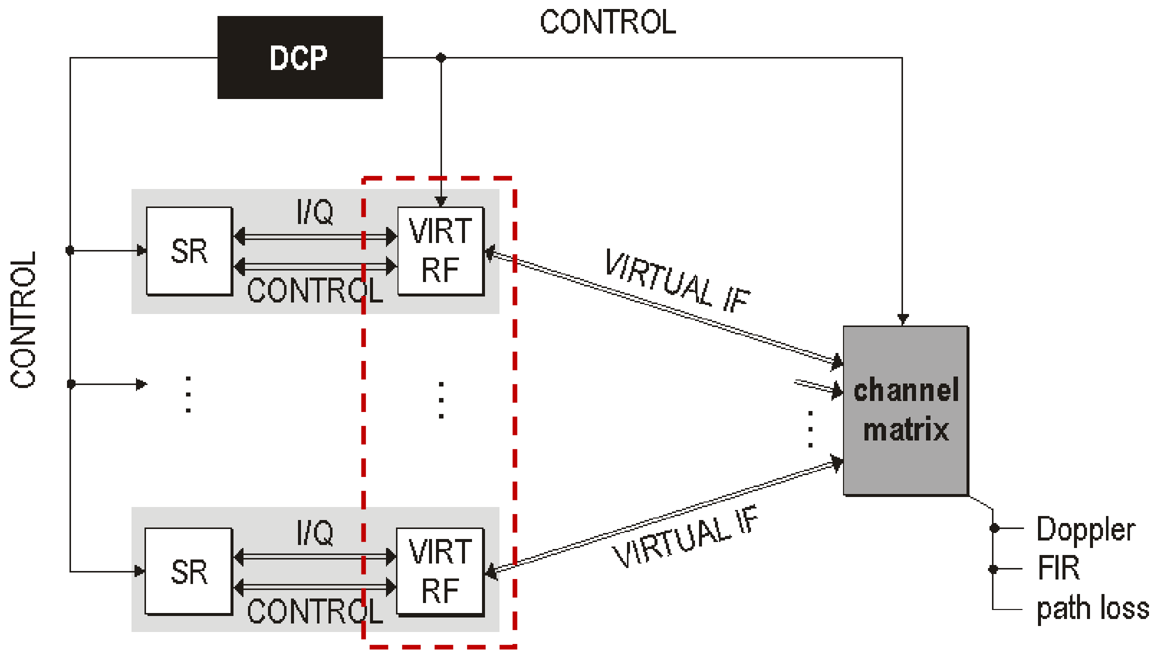


Design Concepts: Components Virtual Mode

Virtual radio front-end models analogue processing.

Virtual radio front-end (Virt RF)

- **Simulates signal path from I/Q base band to antenna**
- **Models non-idealities of analogue processing**

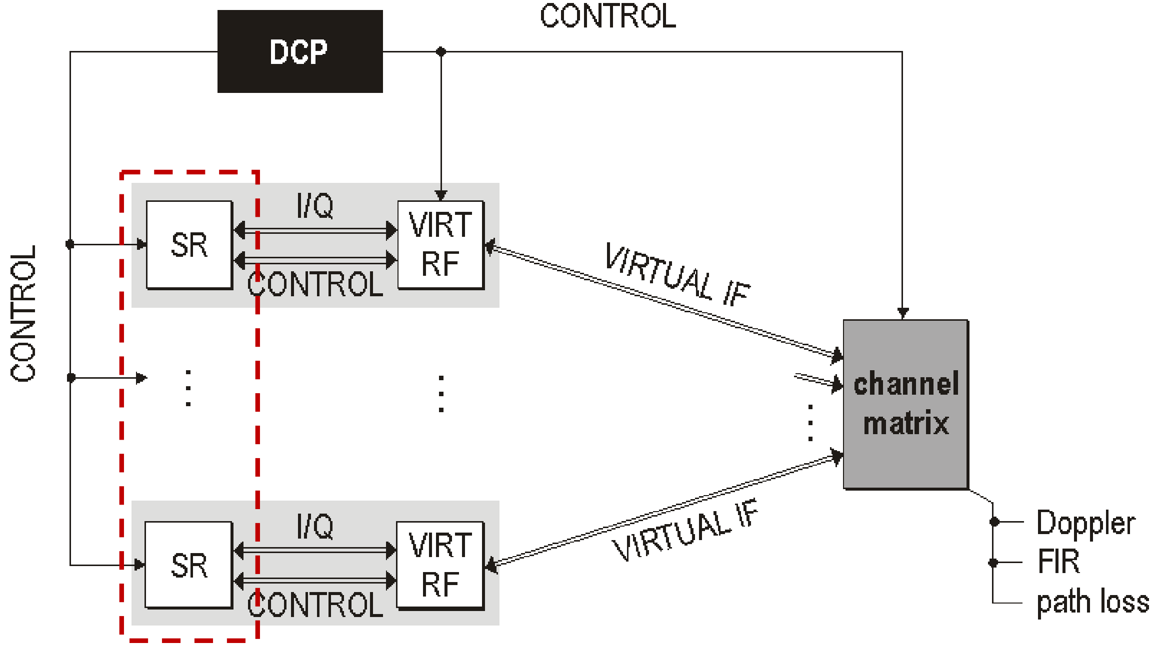


Design Concepts: Components Virtual Mode

SR processes provide I/Q base band processing, transmit and receive path.

Software Radio (SR) terminals

- **SR terminals process I/Q base band samples, send and receive**
- **Control (virtual) RF front-end parameters, such as frequency, gain, transmit power etc.**
- **SR terminal processes interact through virtual RF and channel matrix**

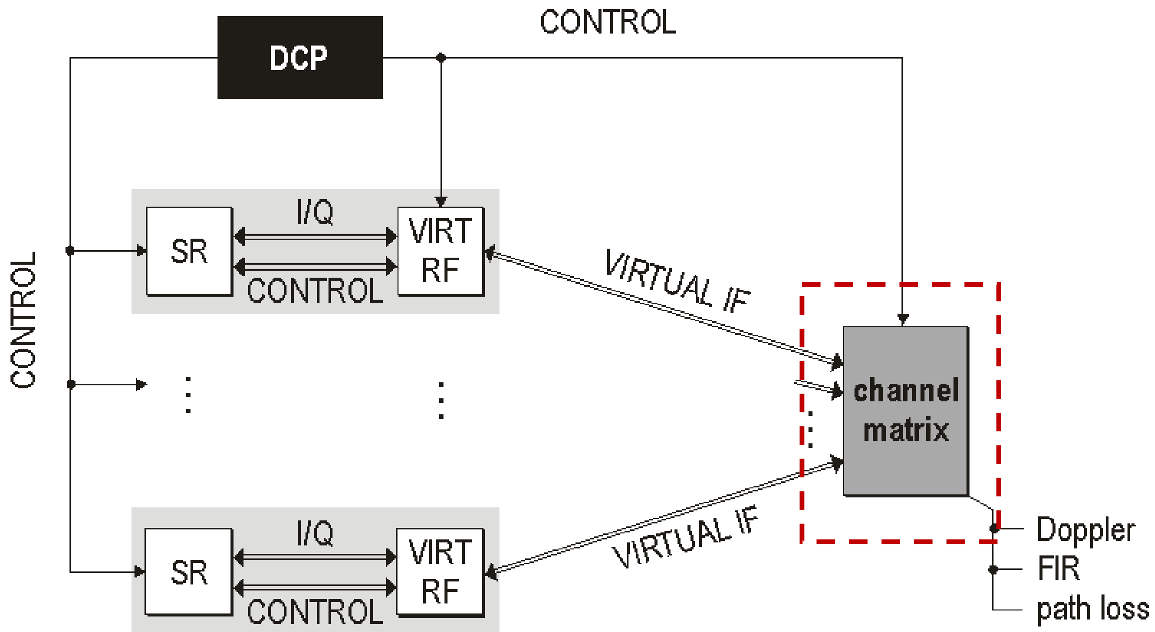


Design Concepts: Components Virtual Mode

The channel matrix models antenna to antenna wave propagation.

The channel

- **Channel matrix simulates the propagation path from antenna to antenna**
- **Parameterized by the DCP according to a world model**
- **Adds and redistributes I/Q streams from SRs**



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Implementation: Software / Hardware Tools

Choice of SR framework: GNU Radio and Ettus Research USRP.

Tools

Virtual Mode Software

- SR terminals
- RF software API: USRP-based
- Channel

Real Mode Software and Hardware

- Ettus USRP1 or USRP2
    - GNU Radio Python USRP interface

GNU Radio
the gnu software radio

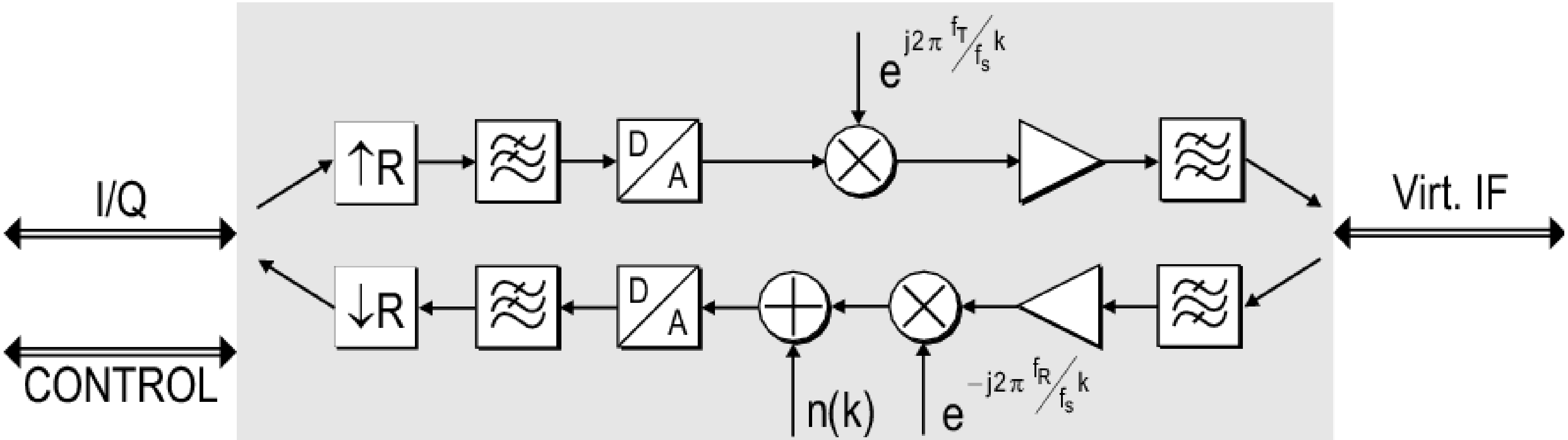
See Ettus Research LLC (http://ettus.com) and GNU Radio (http://gnuradio.org/trac/)

Implementation: Virt RF

Virtual RF front-end signal processing is a hierarchical GNU Radio block.

Virtual RF front-end

- Implemented as GNU Radio signal processing block
- Models internal USRP structure (DUC, DAC) and analogue processing
- Resulting digital signal is upsampled to simulation bandwidth (virtual IF)

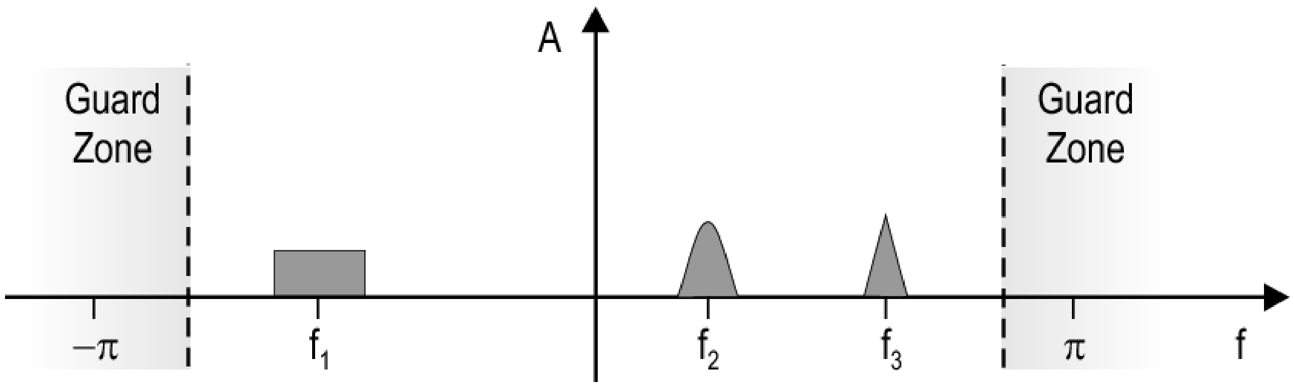


Implementation: Virt RF interpolation

Simulation bandwidth is shared by all SR terminals.

Virtual RF front-end and simulation bandwidth

- Virtual USRP interpolates to DAC rate, 128 MSamples/s
- Simulation bandwidth: 128 MHz
- Interpolation CIC/FIR-based, factor 4 – 512 (USRP1)
- I/Q base band rates from 250 kHz to 32 MHz
- Decimation accordingly as in USRP1



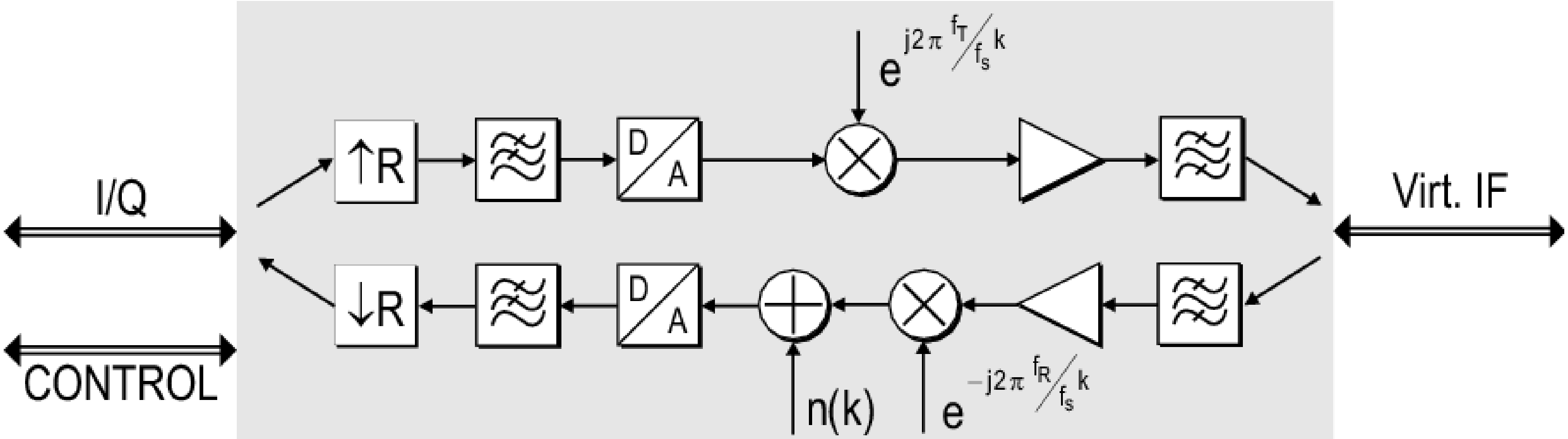
Simulation bandwidth with three SR terminals operating

Implementation: Virt RF modeled non-idealities

Virtual RF front-end models radio non-idealities .

Virtual RF front-end non-idealities

- Digital to Analog, Analog to Digital conversion: Quantization effects
- Frequency offset, drift
- Phase noise
- Non-linear amplification
- Analogue filtering
- Johnson noise

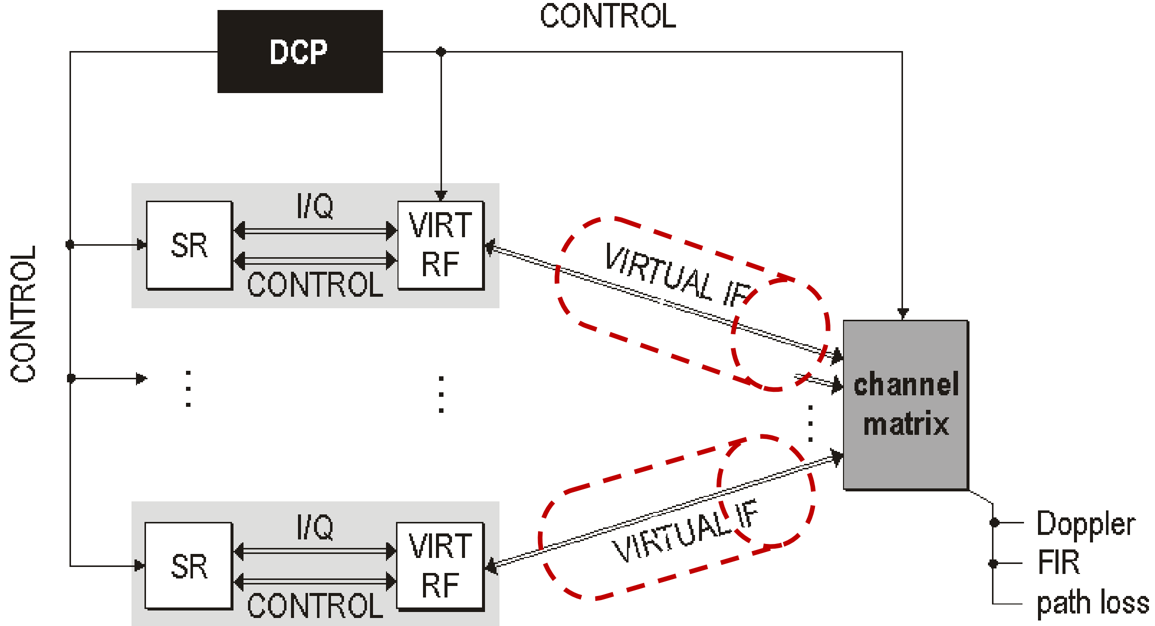


Implementation: Virt RF / channel API

SR terminal / Channel processes communicate via named pipes.

Data transfer between Virtual RF and Channel Matrix

- **Each SR terminal process interacts with channel matrix via named pipes**
    - FIFO buffer for inter-process communication
- **Channel matrix synchronizes streams on a sample per sample basis**
    - SR terminals provide streaming I/Q at simulation bandwidth



Implementation: Channel matrix

Channel matrix is hierarchical block: Time variant FIR tapped delay line model.

Channel Matrix

- The entirety of channels can between N SR terminals can be written in a NxN matrix of impulse responses

$$\mathbf{H}_{\mathrm{Chan}} = \begin{pmatrix} h_{1,1}(t,\tau) & \cdots & h_{1,N}(t,\tau) \\ h_{2,1}(t,\tau) & & \vdots \\ \vdots & \ddots & \vdots \\ h_{N,1}(t,\tau) & \cdots & h_{N,N}(t,\tau) \end{pmatrix}$$

- Modeled effects:
  - Free space loss
  - Multi-path propagation
  - Doppler spread

- Resulting signal at terminal k is calculated via summation of filtered signals

$$r_k(t) = \sum_{l=1}^{N} s_l(t) * h_{l,k}(t,\tau)$$

Overview

Wireless Networks In-the-Loop: Software Radio as the Enabler

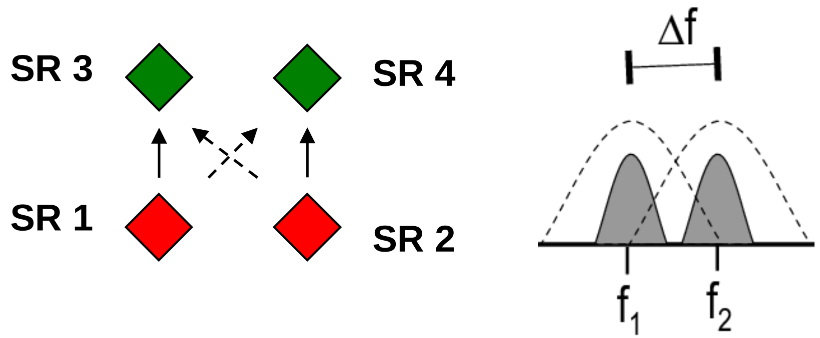
Sample Network: Checking consistency

A simple SR network with 4 SR terminals is simulated.

Simulating an SR network

- Test consistency between Real Mode and Virtual Mode with a simple SR network setup
    - Virtual mode: simulation
    - Real mode: measurement
- Here: Realistic packet error rate analysis under co-channel interference for a complete SR terminal stack
- Transmitters: SR 1, SR 2, receivers: SR 3, SR 4
- Frequency flat fading assumed

Network setup



$$\mathrm{H}_{\mathrm{Chan}} = \begin{pmatrix} 0 & 0 & h_{1,3} & h_{1,4} \\ 0 & 0 & h_{2,3} & h_{2,4} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

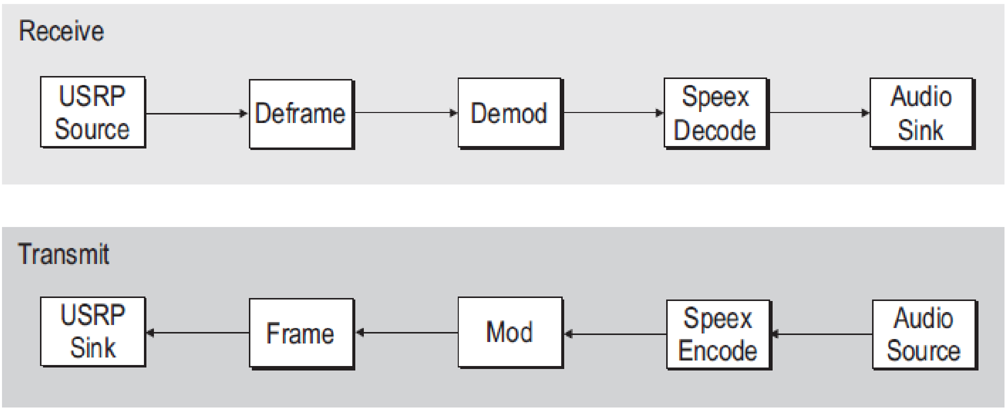
Sample Network: Checking consistency

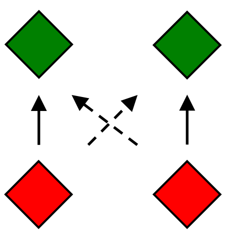
A simple SR network with 4 SR terminals is simulated.

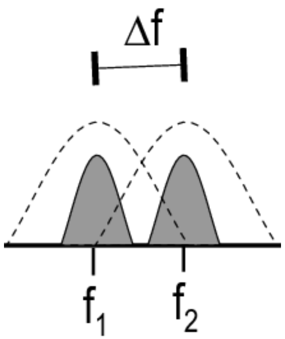
SR terminal code

- Flow graph for each terminal uses standard GNU Radio framing/deframing, modulation
  - GMSK on PHY
- Custom code for Speex
  - Narrow band codec for speech
  - Supports Packet-loss concealment
- No channel coding used

Flow graph







See Speex: A Free Codec for Speech, http://www.speex.org

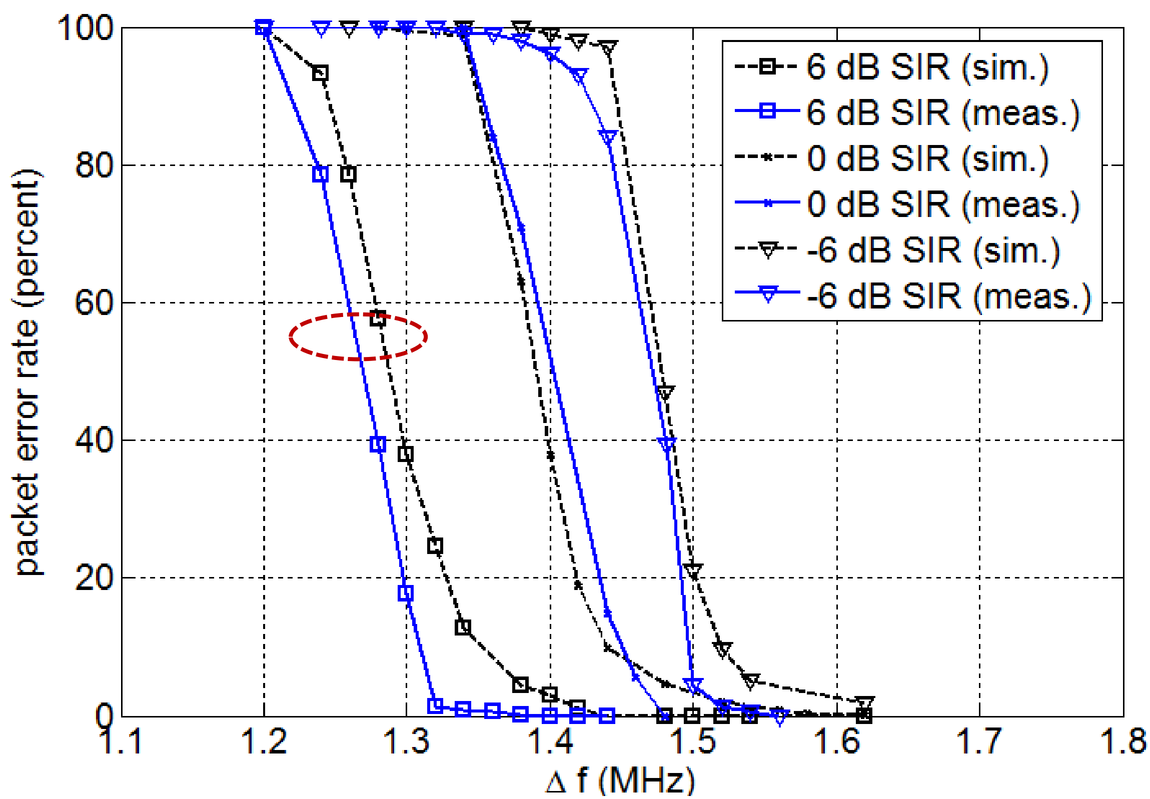
Sample Network: Checking consistency

A simple SR network with 4 SR terminals is verified by measurement.

Simulation and Measurement results

Modulation	: GMSK
Interpolation	: 64
Decimation	: 64
Samples/Symbol	: 2
Bit Rate	: 1 Mb/s
Tx1 SNR	: 22 dB
Tx2 SNR	: Varied
Signal BW	: 1.5MHz
RF Filter	: 2 MHz

SIR : Signal to Interference Ratio is calculated as Rx power of SR 1 to Rx power of SR 2 at SR 3



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Conclusion and Future Work

Wireless Networks In-the-Loop: On going work.

So far…

- Framework, sample implementation of a wireless network simulator, allowing loop-testing of wireless networks
  - Simple USRP abstraction
- Needed for verifiable performance testing of SR networks
  - Especially for ad hoc or overlay networks: evaluation of Interference
- Code under development

Goal: free network simulator

Future Work

- Introducing an absolute time reference
  - Sample-based synchronization is a kludge
- Improving performance
- Improving abstraction of hardware (e.g. accurate modeling of RF filters)
- Better demos, …, <your work here>

Q&A / Discussion

Thank you for your attention!