Compressive Wireless Pulse Sensing

CTS 2015 – Internet of Things

Harvard University

Kevin Chen

Harnek Gulati

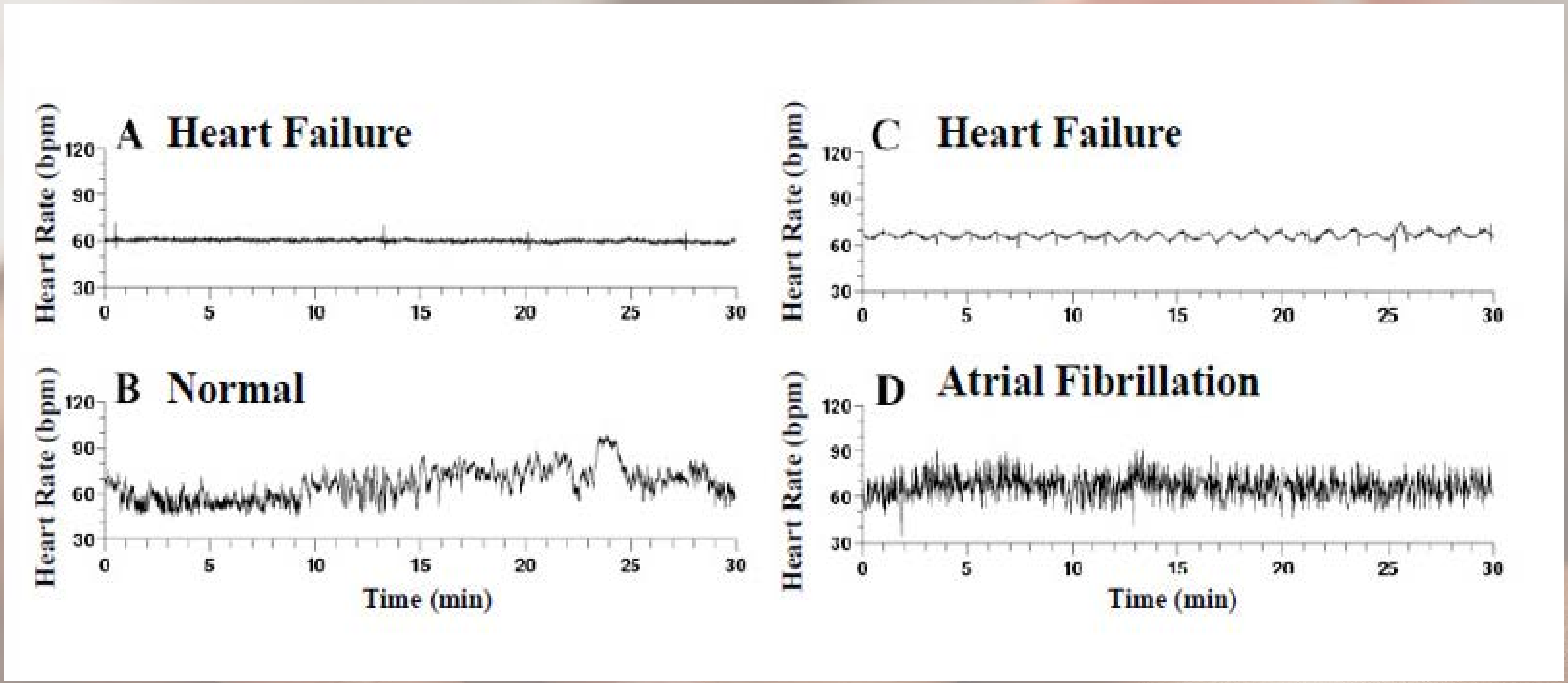
HT Kung

Surat Teerapittayanon

Tracking reliable pulse waves for long term health diagnostics

Motivation

Classification of Heart Health

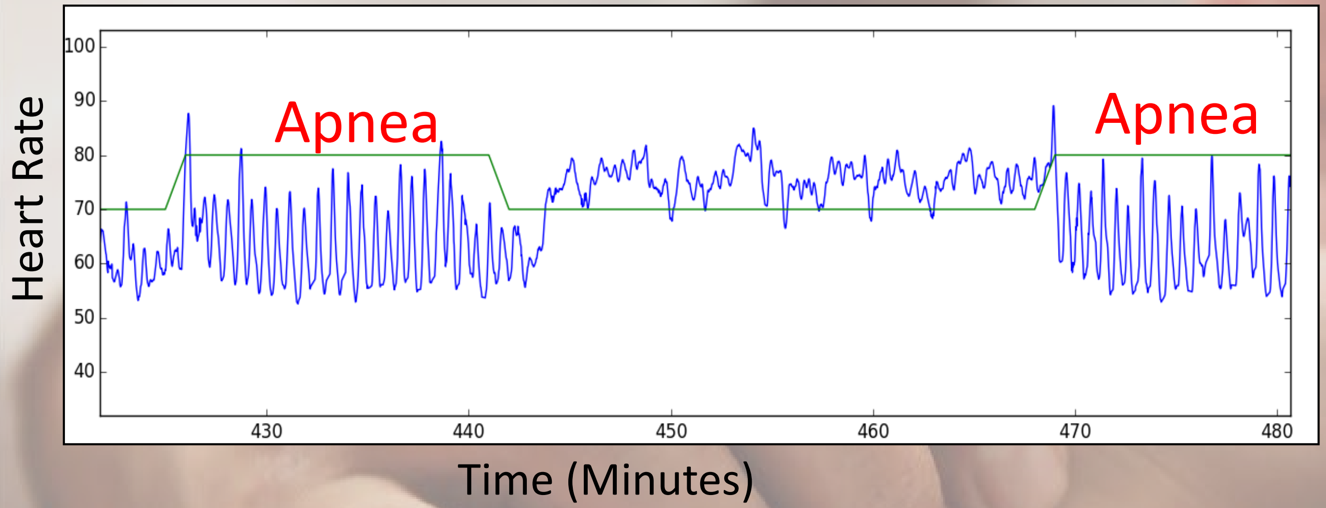


Classification of heart conditions derived from heart rate over time

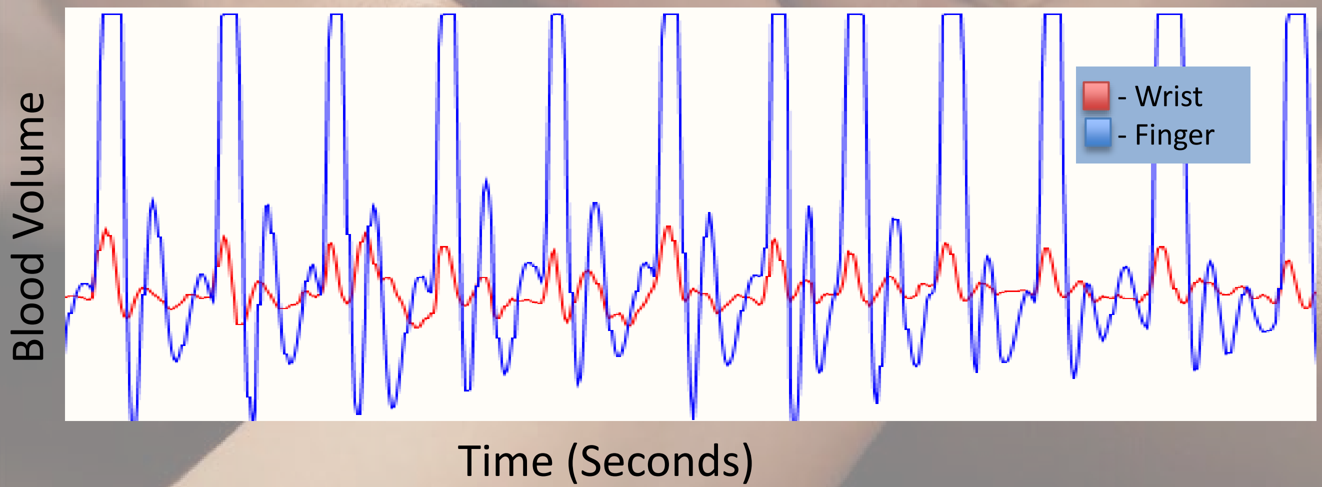
[1] Peng, Chung-Kang. "Toward a General Principle of Health and Disease." Toward a General Principle of Health and Disease. Harvard Medical School, Cambridge. 26 Mar. 2015. Lecture.

Motivation

Diagnostics based on pulse



Sleep apnea diagnosis based on changes in heart rate



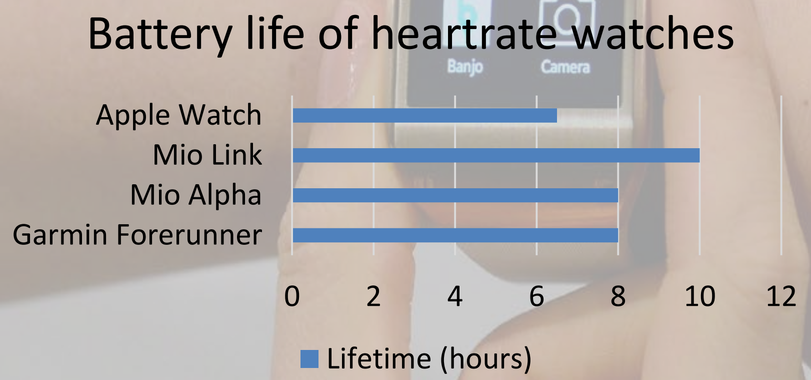
Blood pressure calibration from phase change of PPG signals in two locations

Message

With the recent availability of low-power wireless chips, for the first time, we can monitor pulse waves over a long period of time for applications such as measuring heartrate variability. However, we are still limited by the power budget available on wearables. In this paper, we will show how **we can use compressive sensing to reduce power consumption.**

Problem to Solve

Power Consumption of Wearables



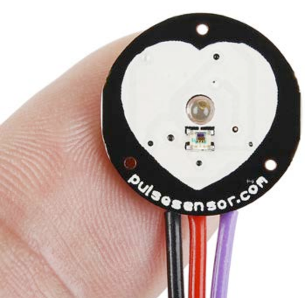
Battery consumption of wearables restricts its ability to continuously monitor pulse wave

With new low-power wireless chips like BLE and additional power-saving compressive sensing techniques of this paper, it is now feasible for battery-powered wearables to monitor pulse wave continuously for days or even weeks.

Overview of System

Tracking reliable pulse waves for long term health diagnostics

Signal Acquisition



Wireless Data Transmission

Signal Analysis

Video Demo of Pulse Wave Reconstruction

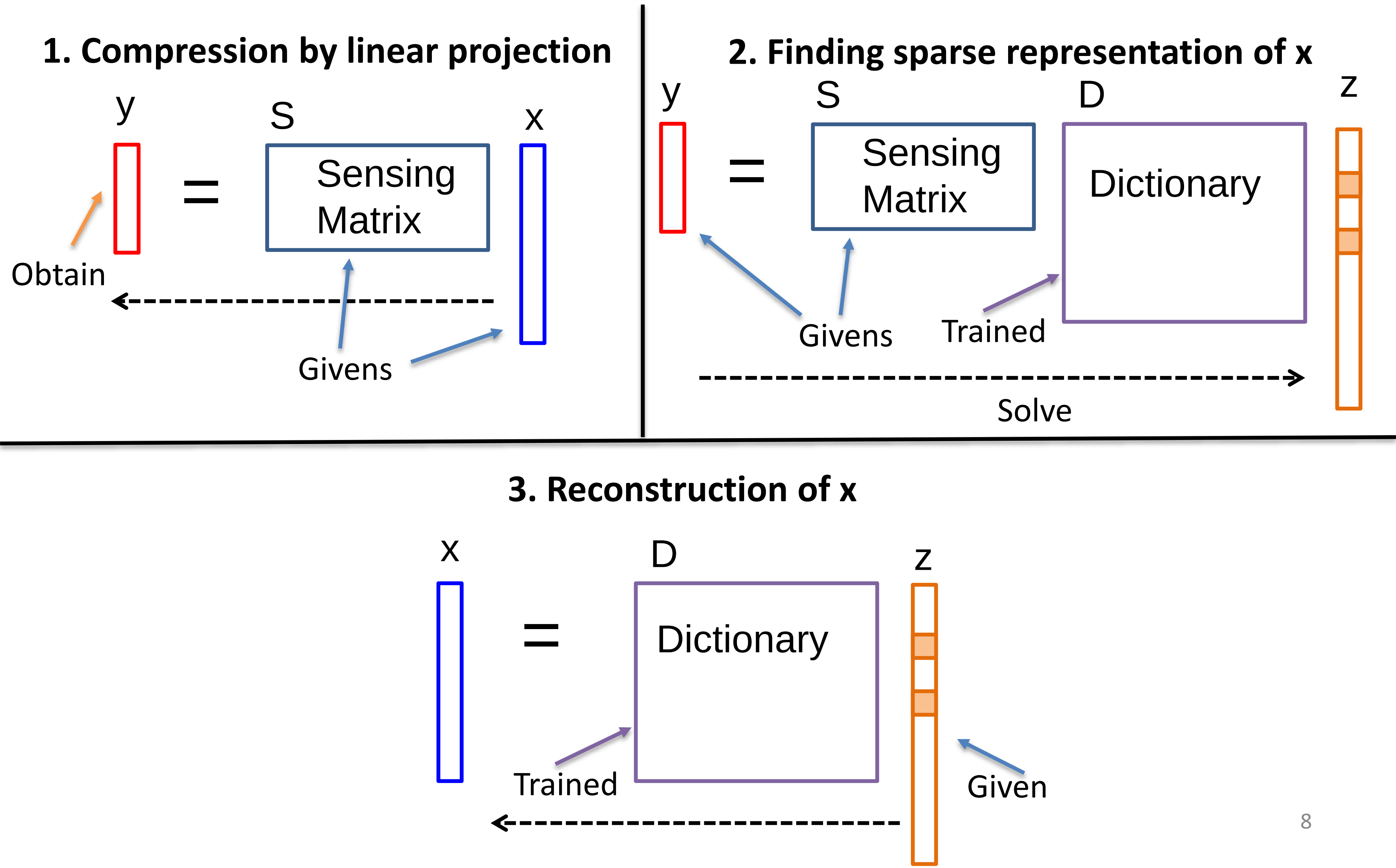
Outline of Presentation

1. Signal Acquisition
   – Compressive sensing for pulse waves
2. Wireless Data Transmission
   – Forward error correction by interleaving and randomization
   – Adaptations in response to channel quality
3. Signal Recovery
   – Reconstruction of pulse wave through sparse coding
   – Noise removal

Part One: Signal Acquisition

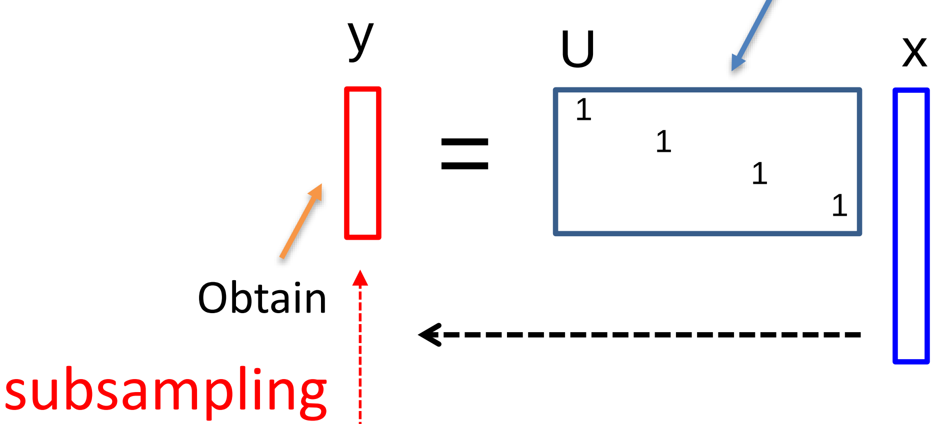
Compressive sensing for pulse waves

Compressive sensing formulation



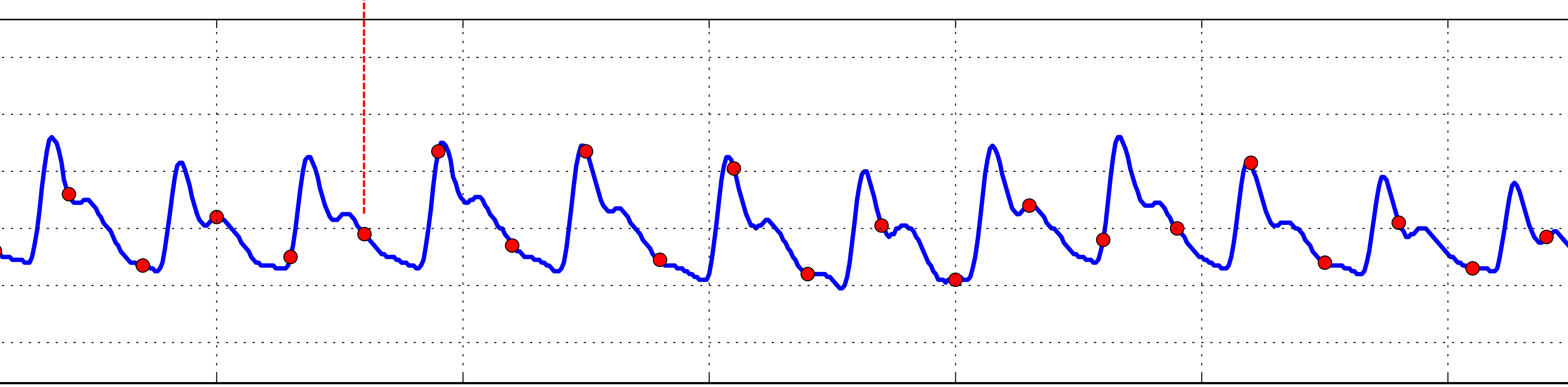
Uniform subsampling to reduce sensor wake-up time

We use uniform subsampling as the sensing matrix

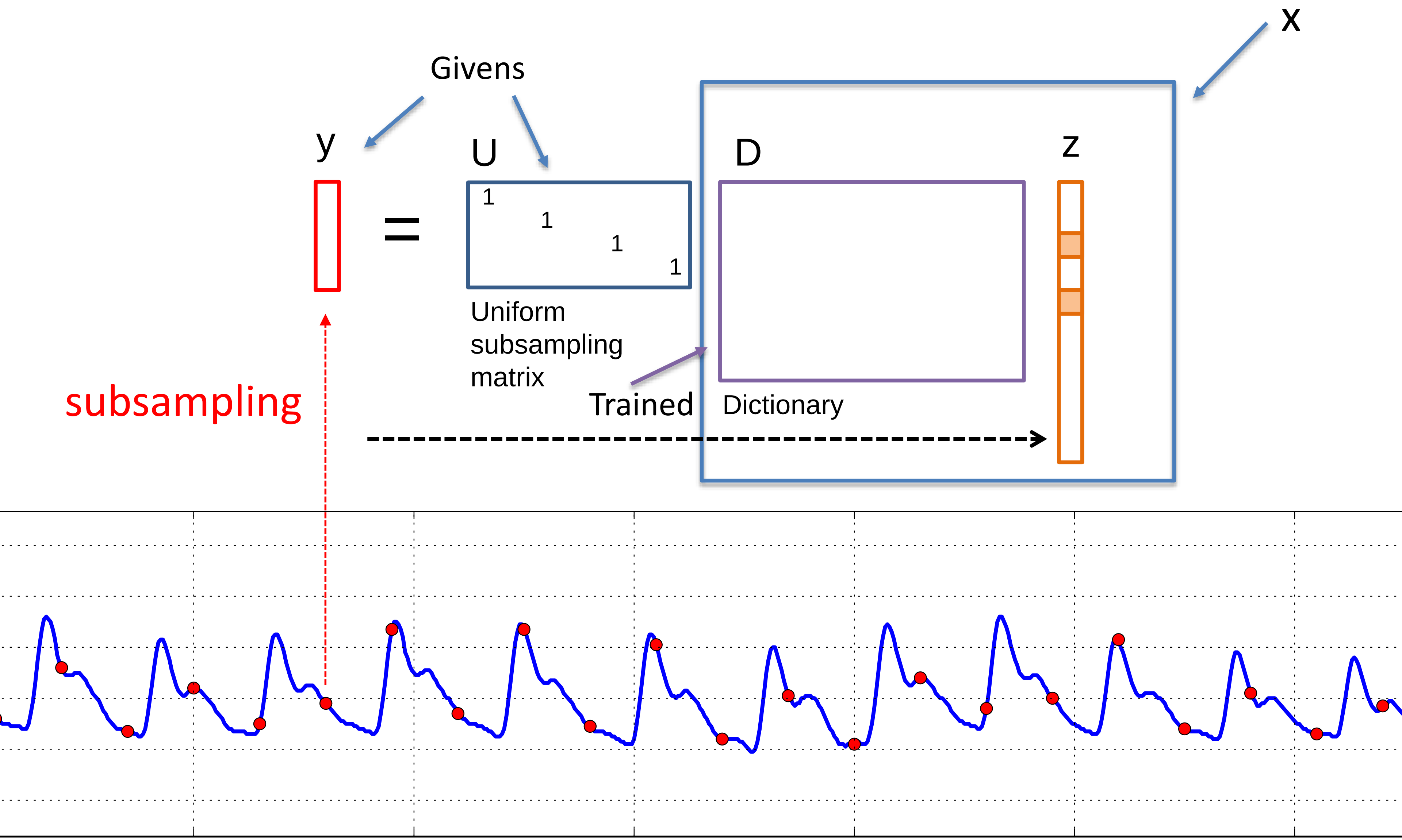


The measurements

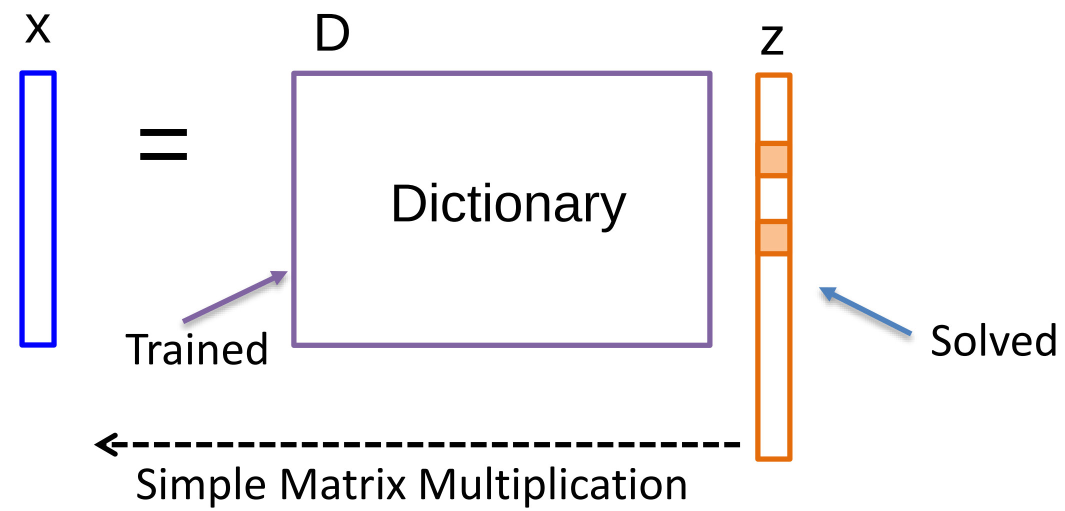
y is a linear projection of **x**

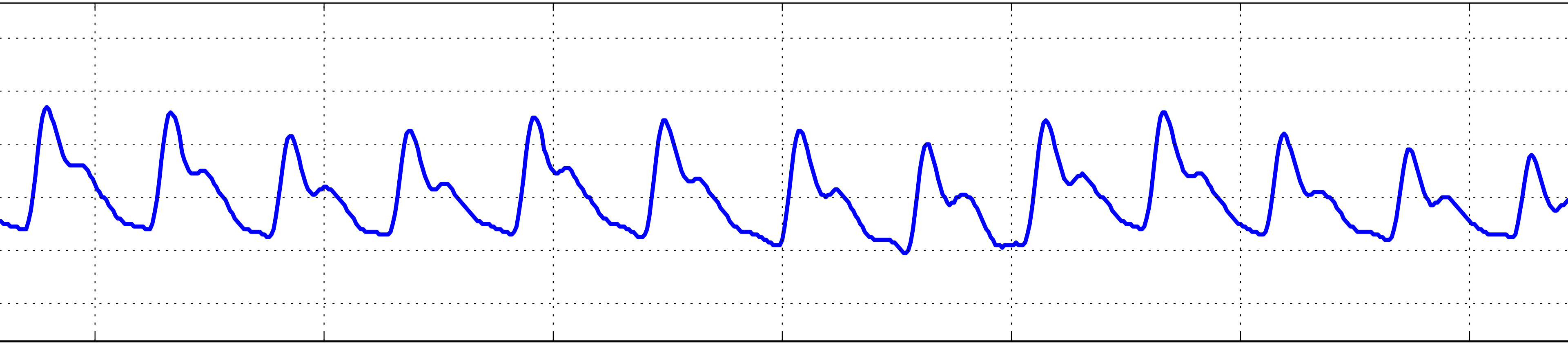


Finding the sparse representation of x



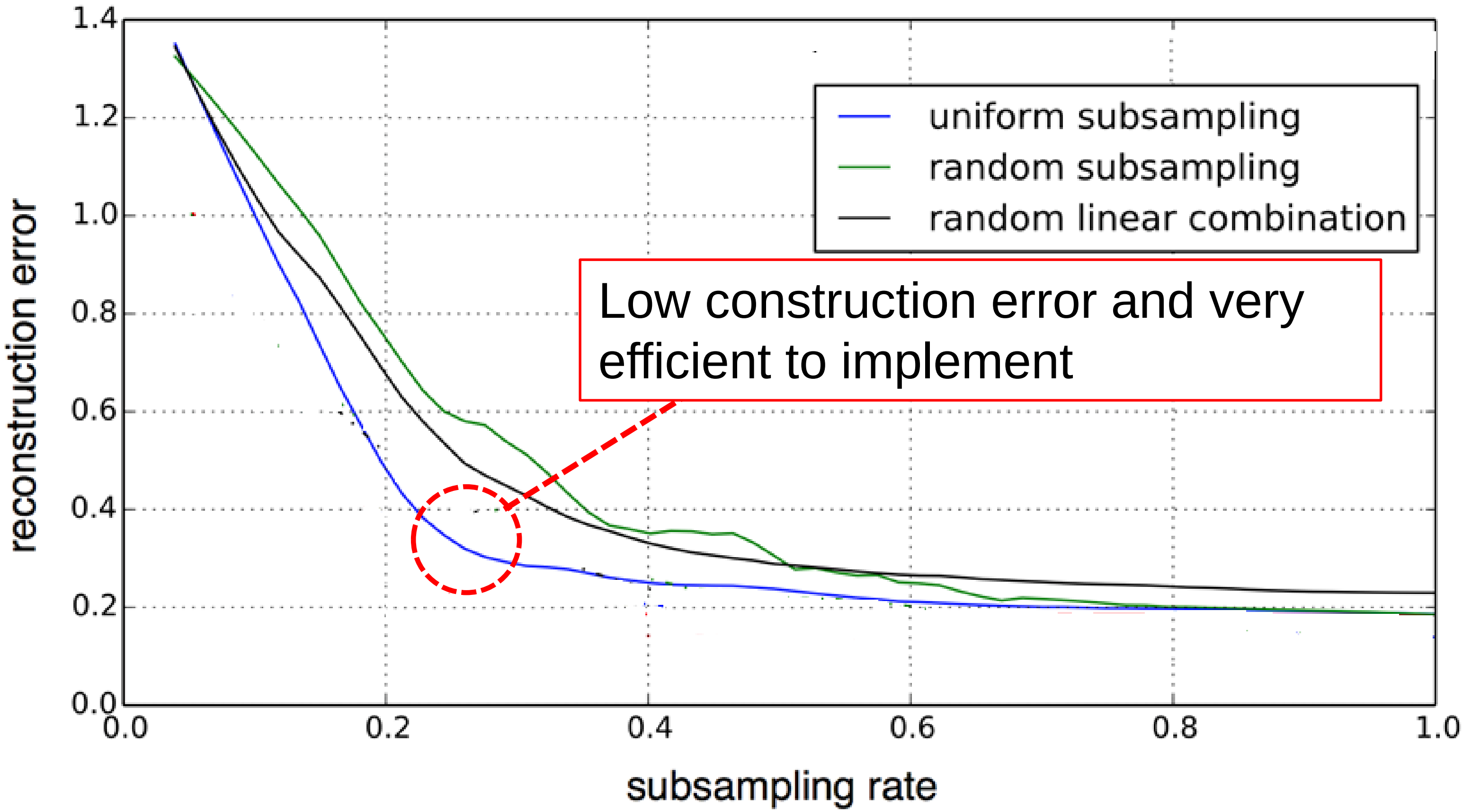
Reconstructing the signal from sparse representation





Experimental Results

With a dictionary trained on pulse waves, uniform subsampling performs better than classic compressive sensing methods.

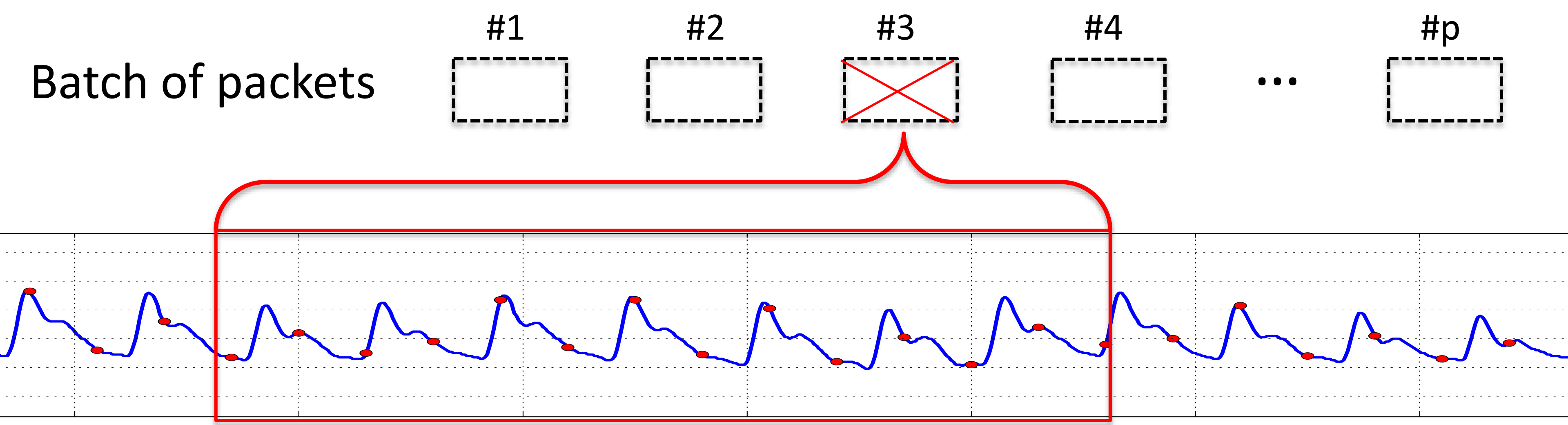


Wireless Data Transmission

- Forward error correction by interleaving and randomization
- Adaptations in response to channel quality

Naïve transmission scheme

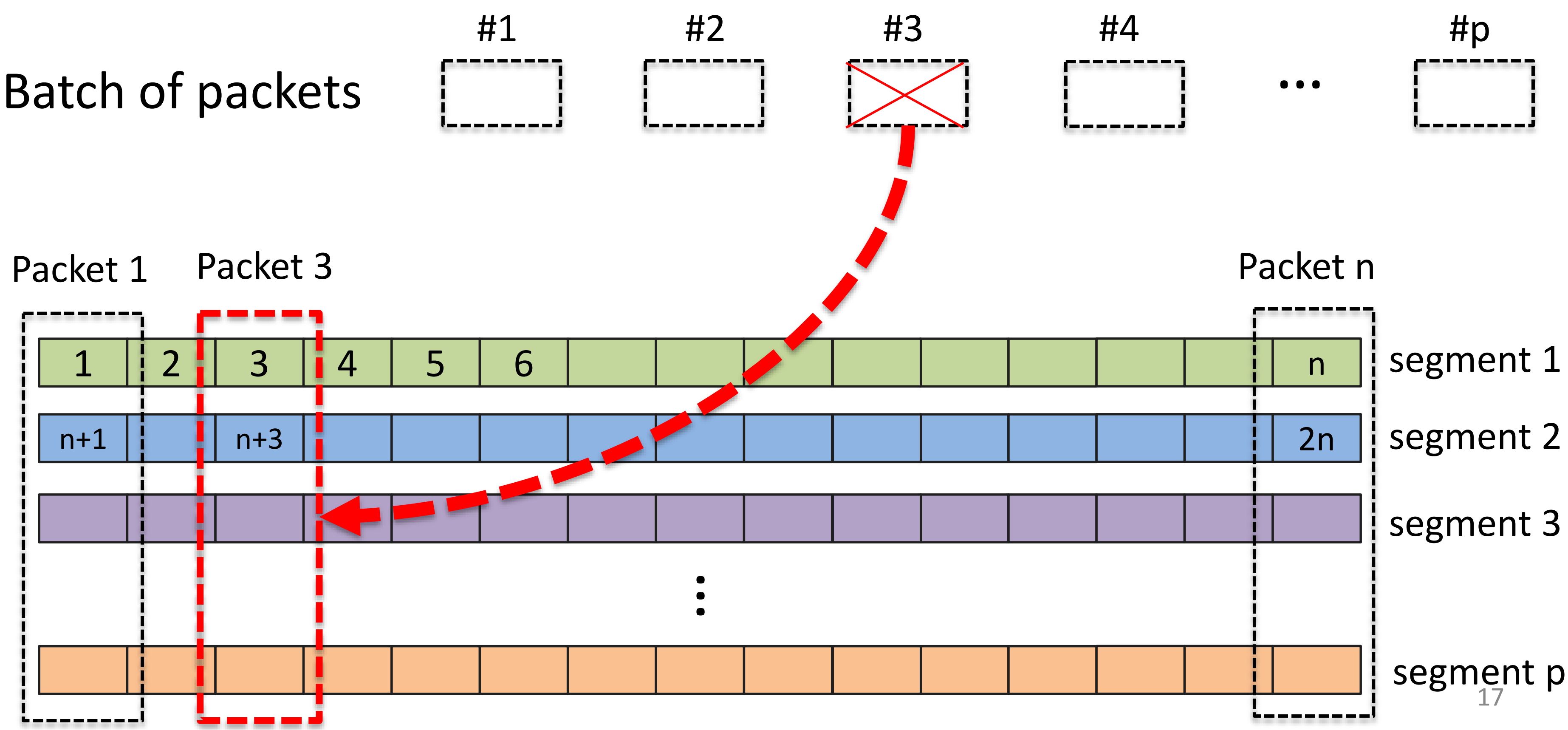
Putting a whole signal segment in one packet is not ideal, because there is no way to recover information without resending



A whole segment of signal is lost

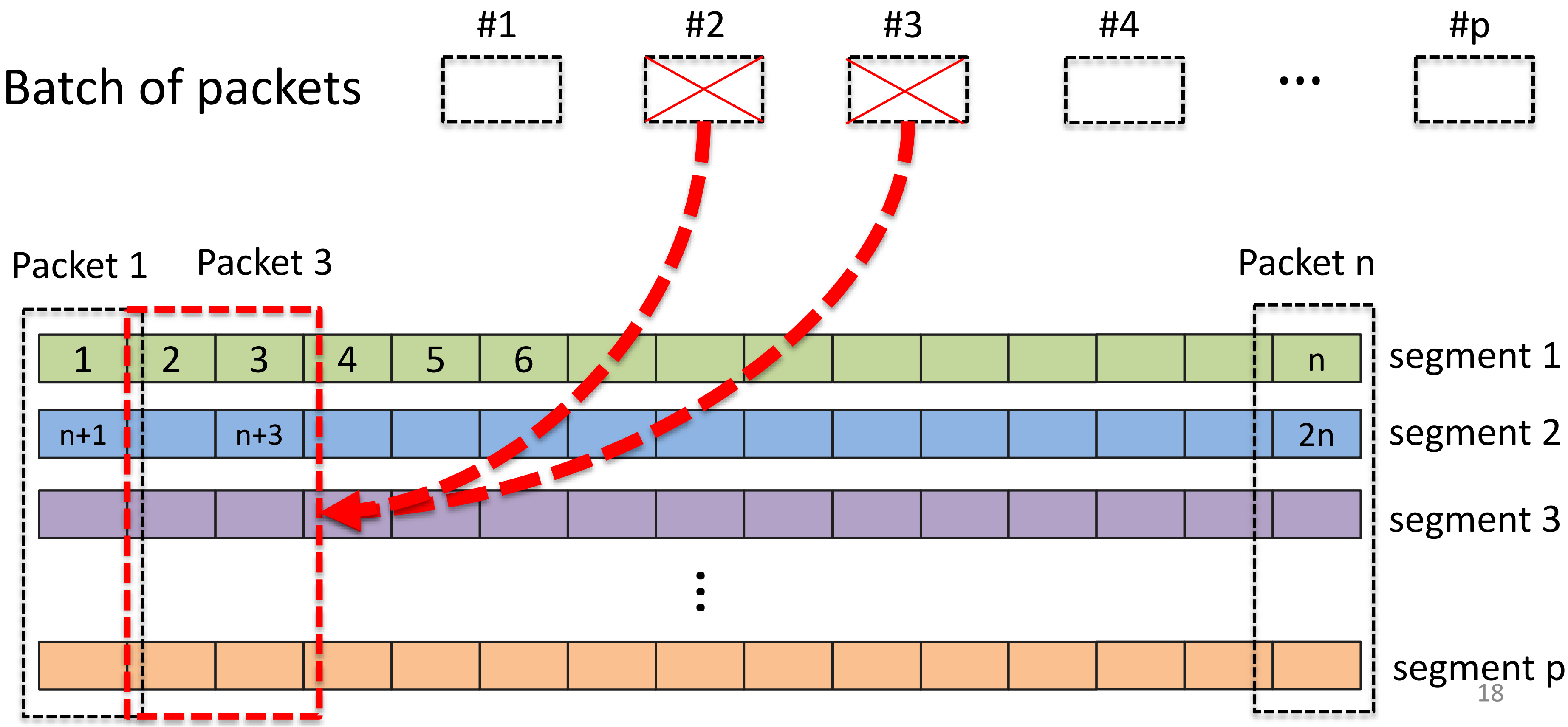
Packet interleaving

By interleaving packets, we can recover the information of lost packet from neighboring received packets.



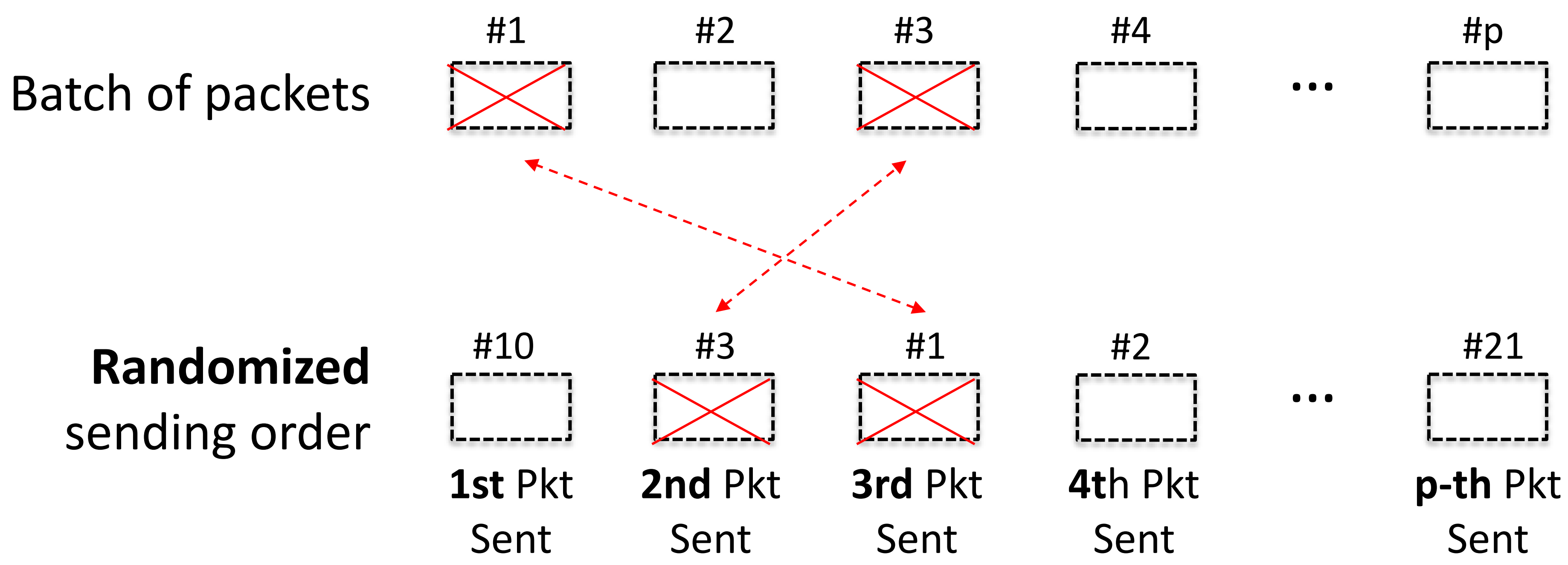
Problems with burst packet loss

However, consecutive packet loss still results in consecutive sample loss in each segment



Randomizing packet sending order

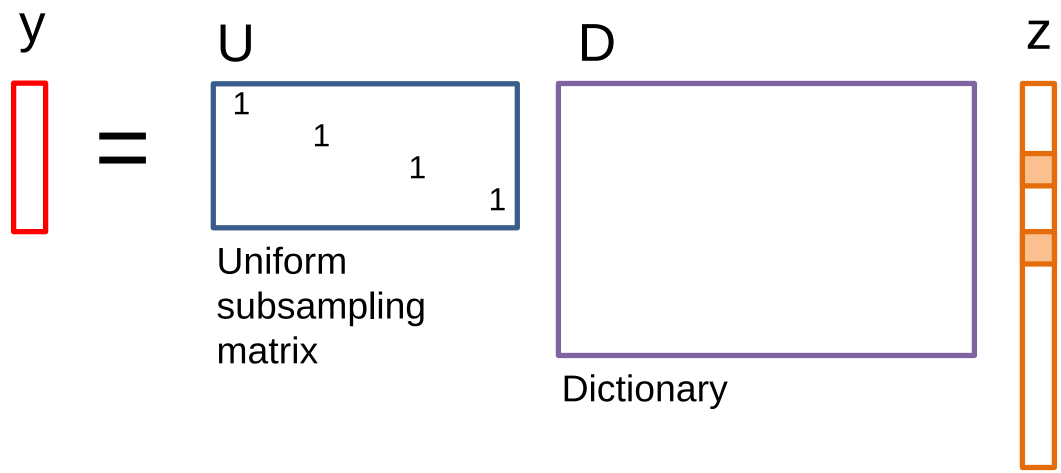
We can avoid consecutive sample loss by sending packets in randomized order



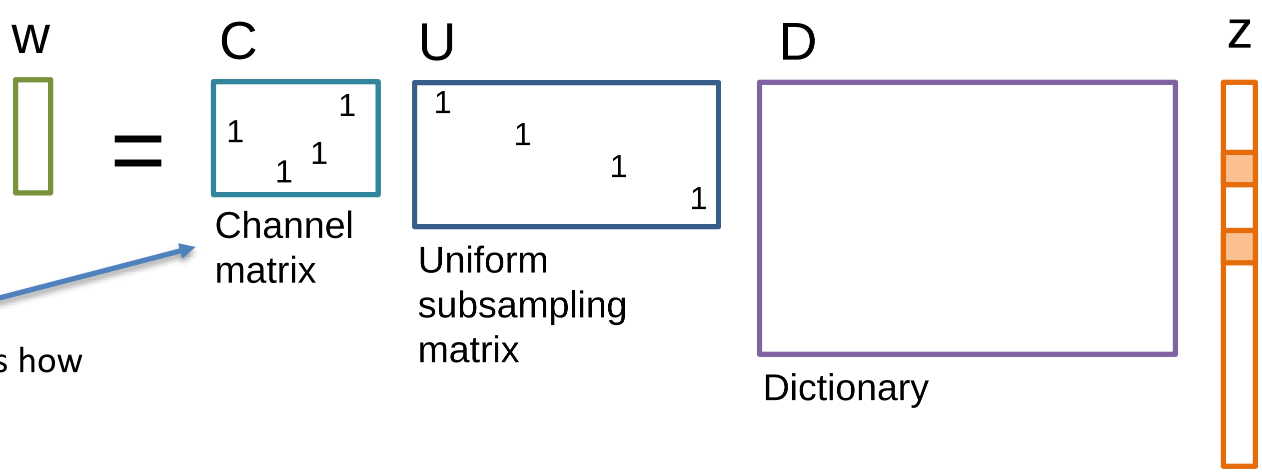
Reconstruction with updated packet transmission scheme

We can represent the packet interleaving as a projection

Before

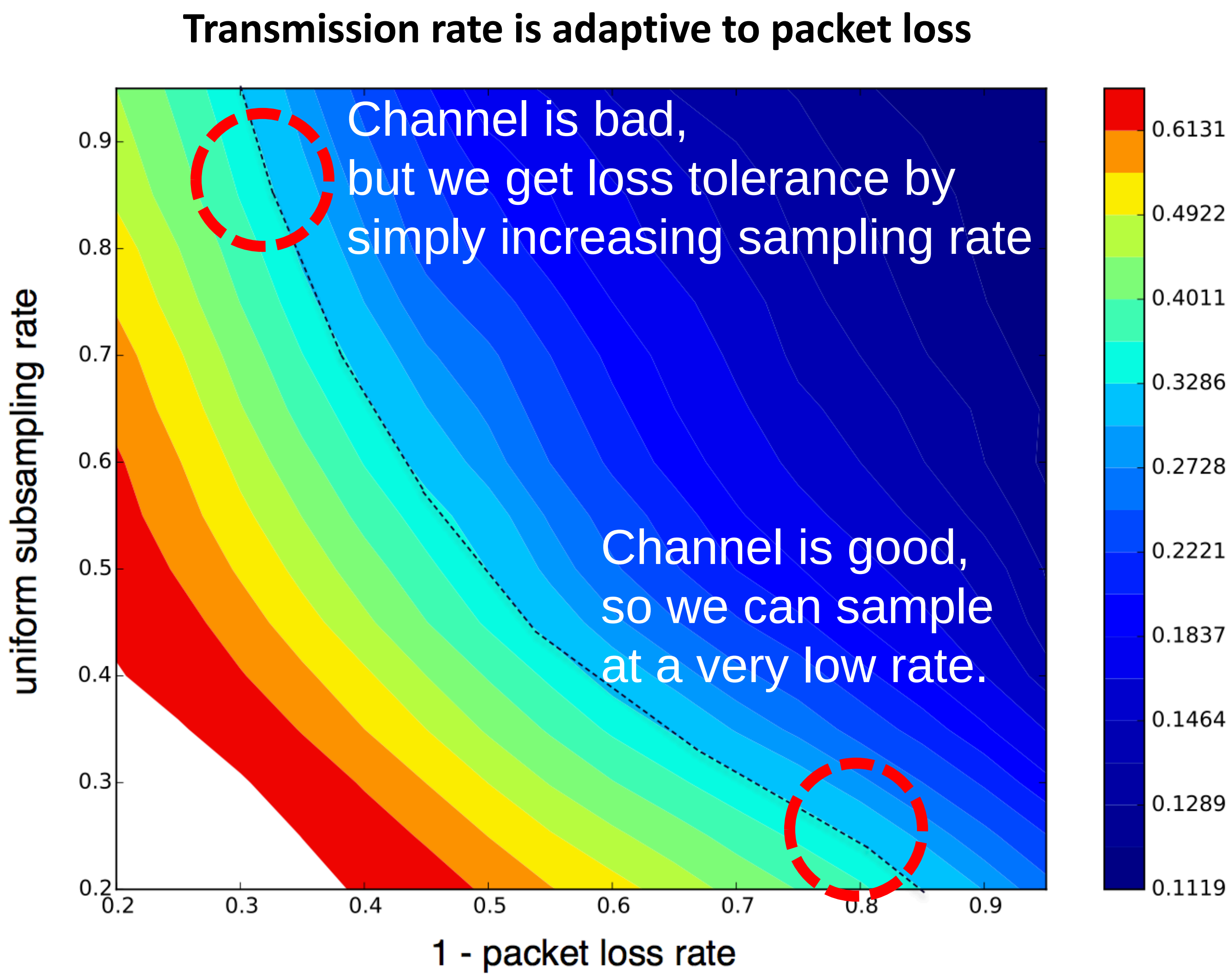


After



Matrix that represents how we interleave packets

Reconstruction error with varying packet loss rates

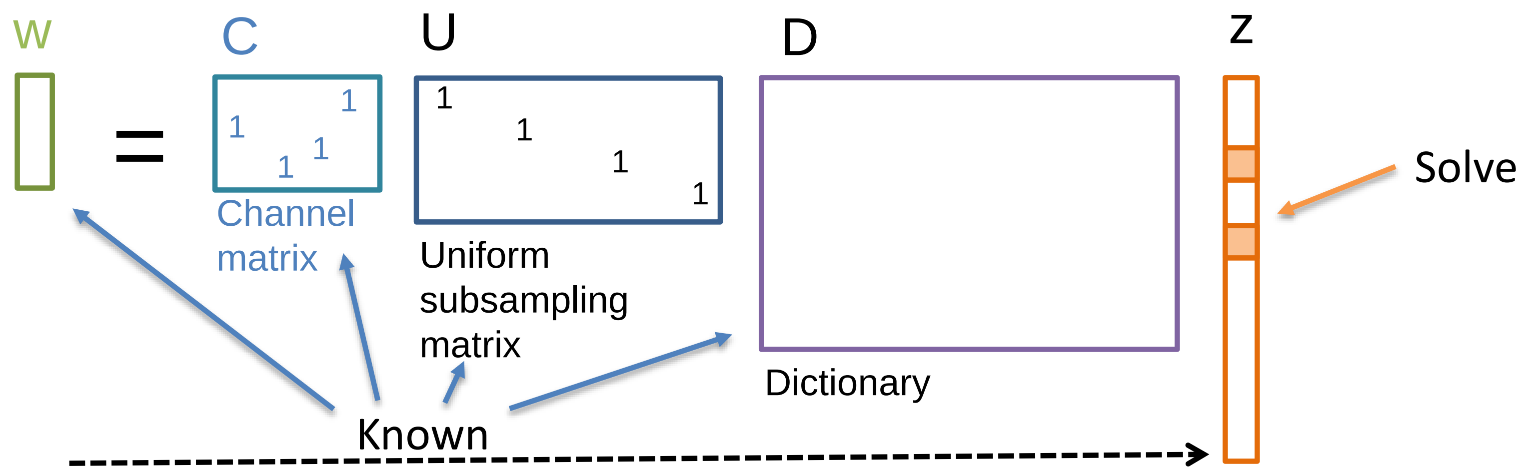


Signal Recovery

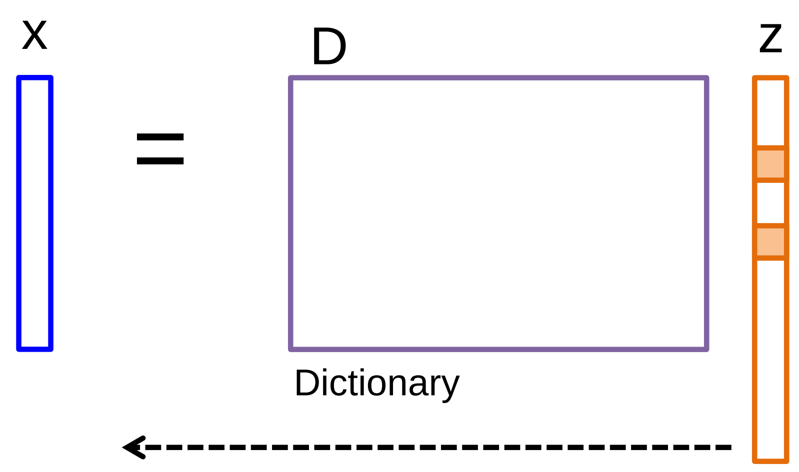
- Reconstruction of pulse wave through sparse coding
- Noise Removal

Reconstructing the signal

1. Use sparse coding to recover z

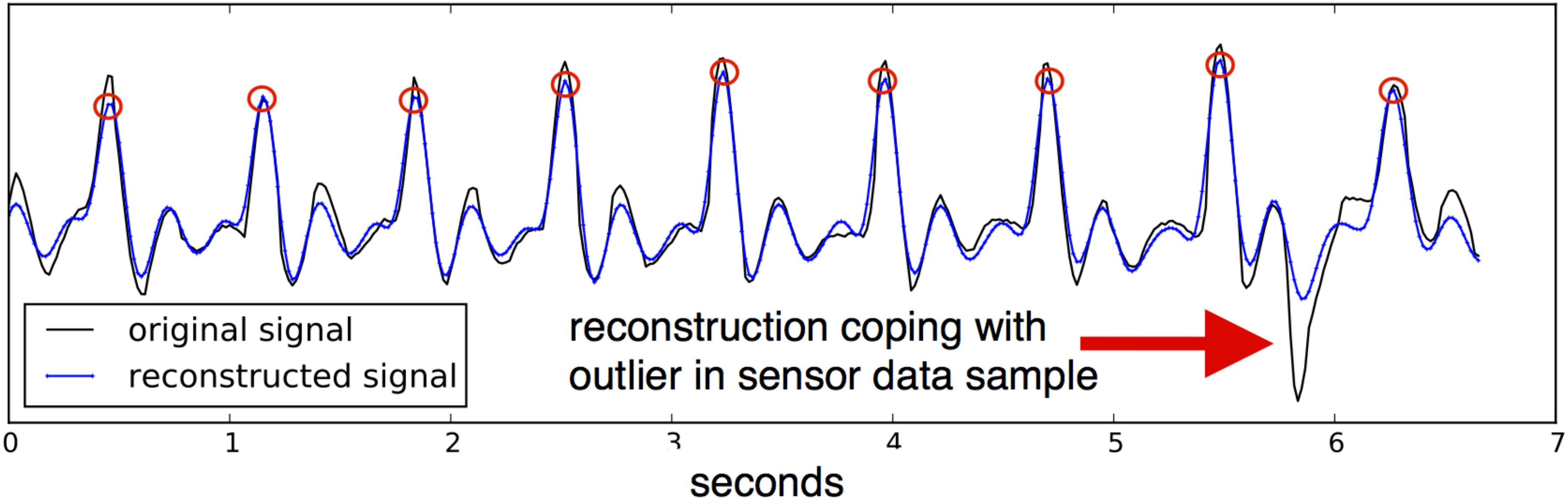


2. Reconstruct x



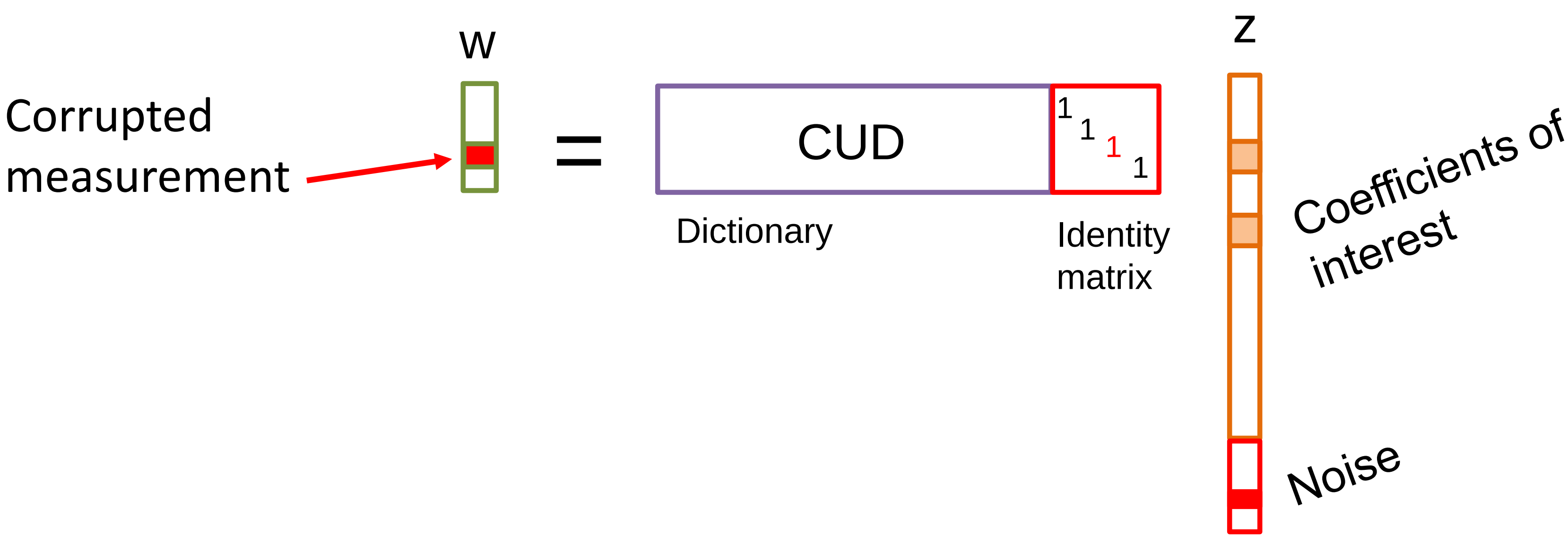
Cleaning the signal from outliers

There can be outliers caused by movements, sensor voltage change, etc.

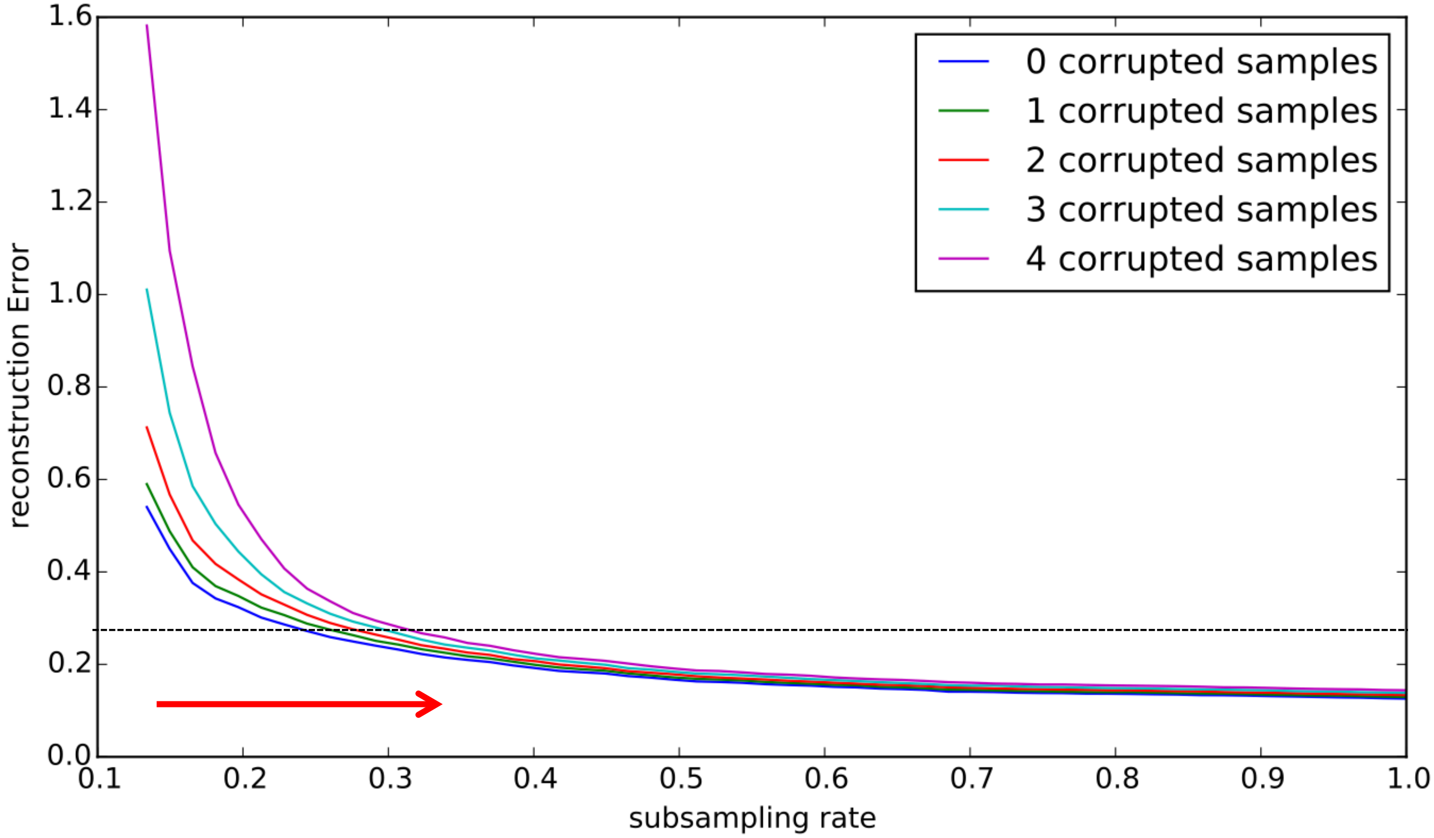


Augmenting the dictionary for noise removal

With a little tweak, we can even tolerate corrupted measurements



Reconstruction error at different noise levels

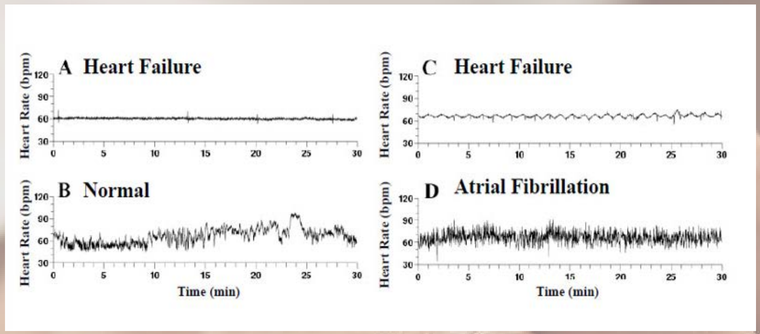


We can deal with corrupted samples
by increasing sampling rate

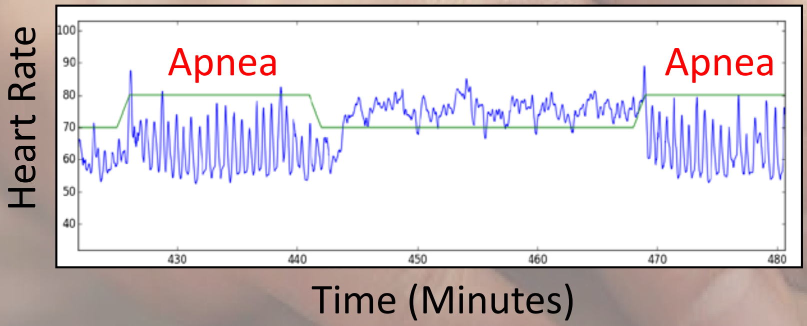
Implications of Our Results

Pulse Diagnostics Readily Available

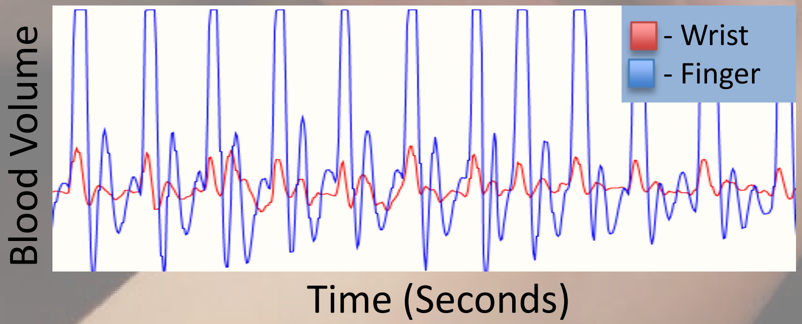
Long term health monitoring made possible



Classification of heart conditions derived from heart rate over time



Sleep Apnea diagnosis based on changes in heart rate



Blood Pressure Calibration from phase change of PPG signals in two locations

Summary

With new BLE chips, continuous health monitoring is possible for the first time

Signal Analysis
Reconstruction
De-noising

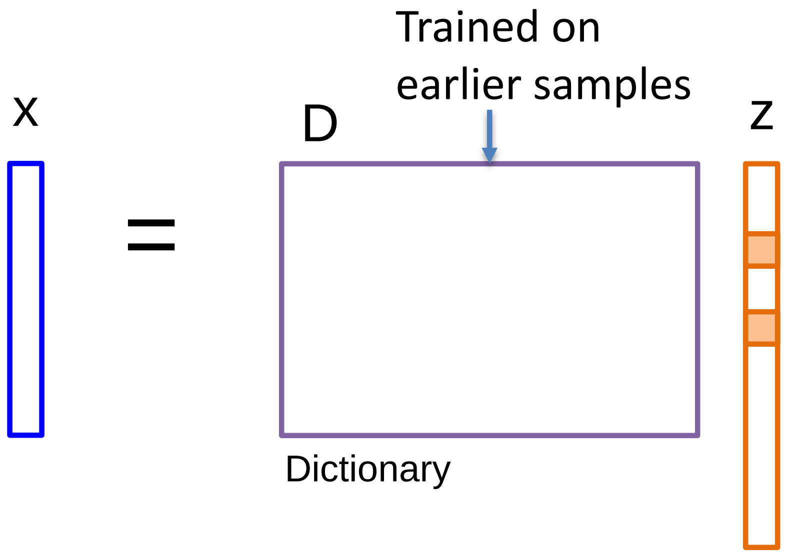
Lower wakeup frequency
Signal Acquisition

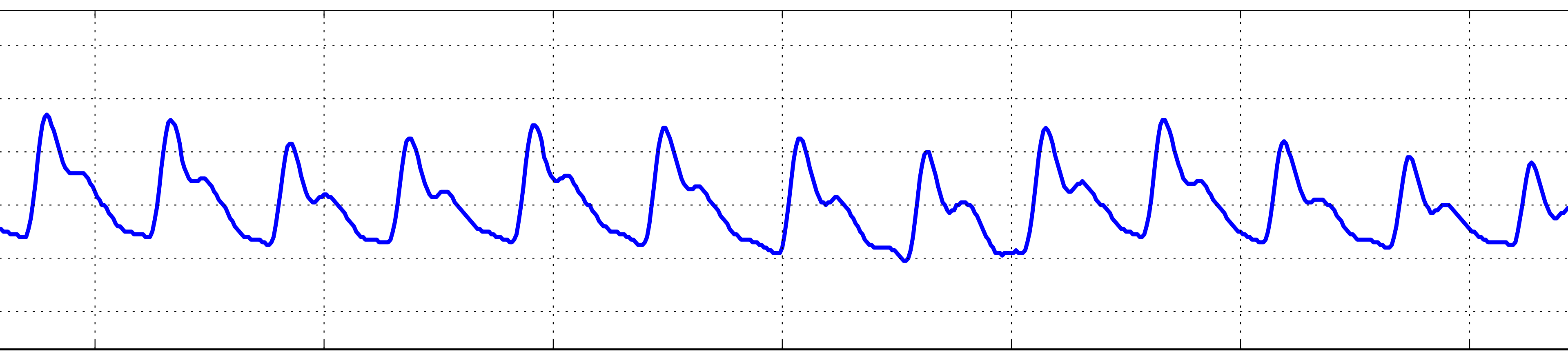
Wireless Data Transmission
Lower transmission rate
Resilience to channel loss

Conclusion

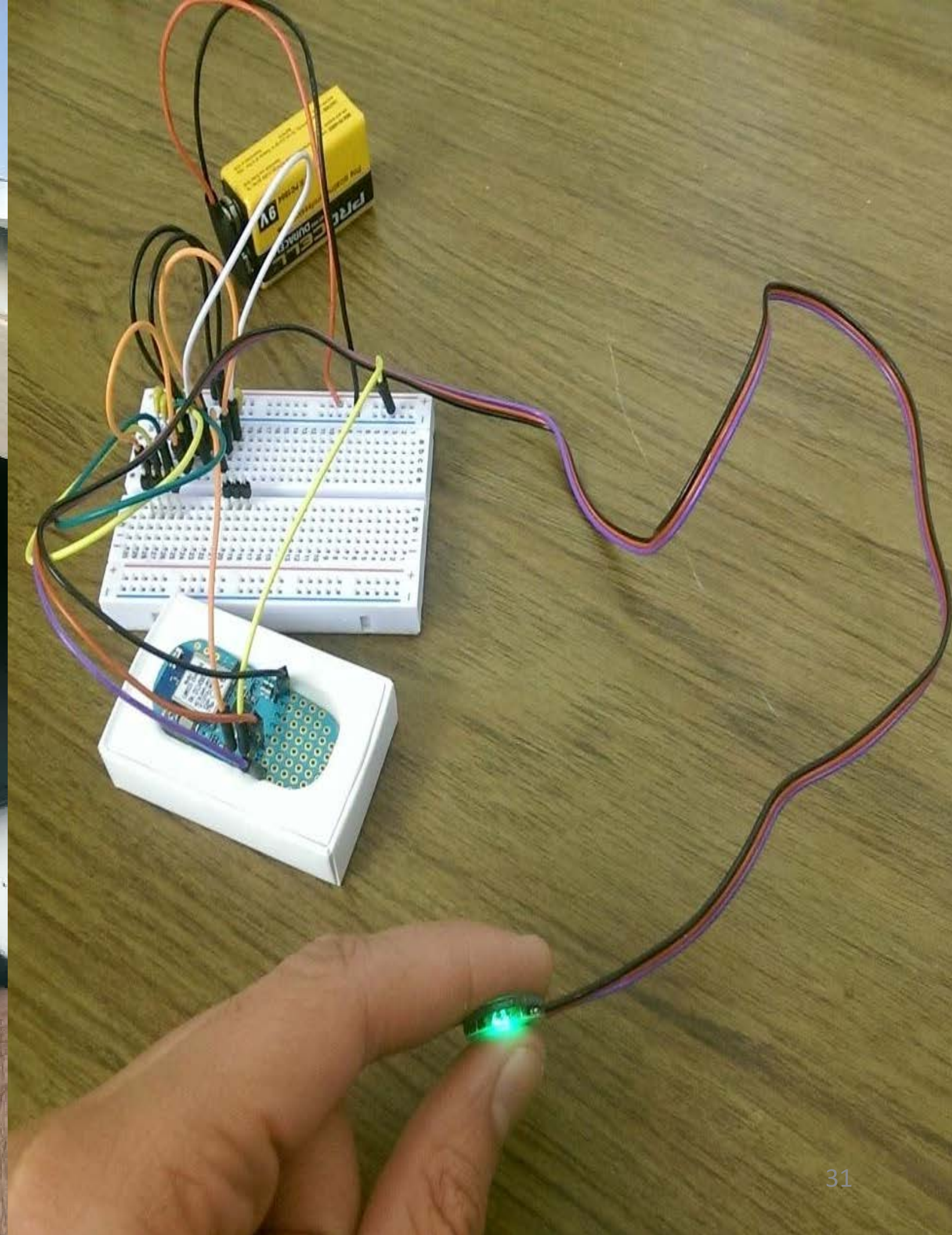
Due to the recent availability of pulse sensing chips, and low-power wireless chips, for the first time we can monitor pulse waves over along period for applications such as measuring heartrate variations. But we have a challenge of coping with limited power budget available on wearables. We have shown in this paper that we can use compressive sensing to reduce power consumption.

Training a dictionary with pulses* (remove?)



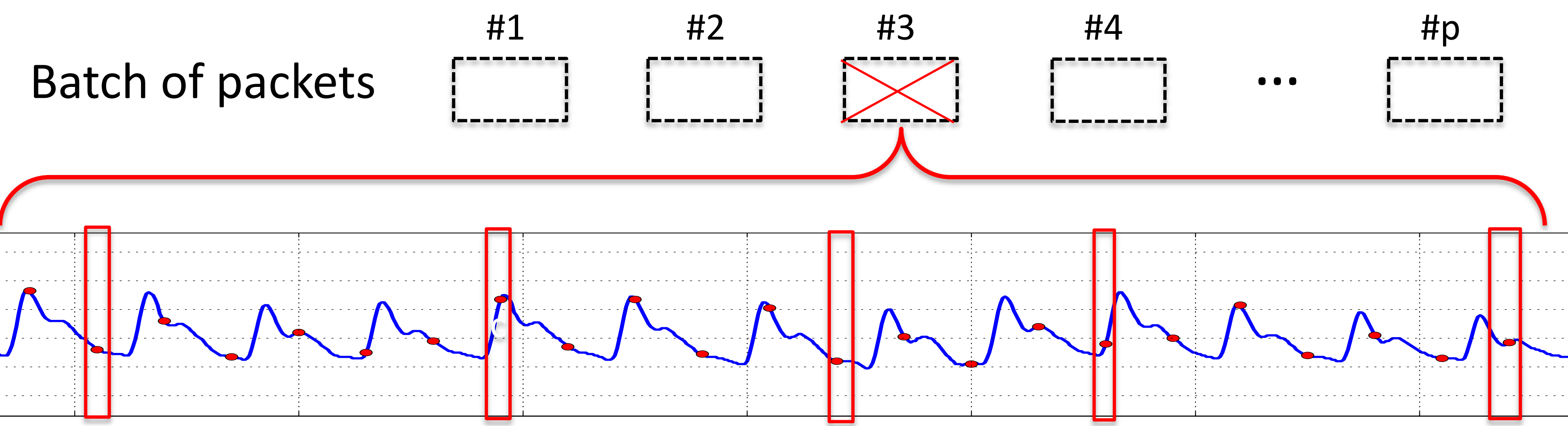



WIRE
CUTTER

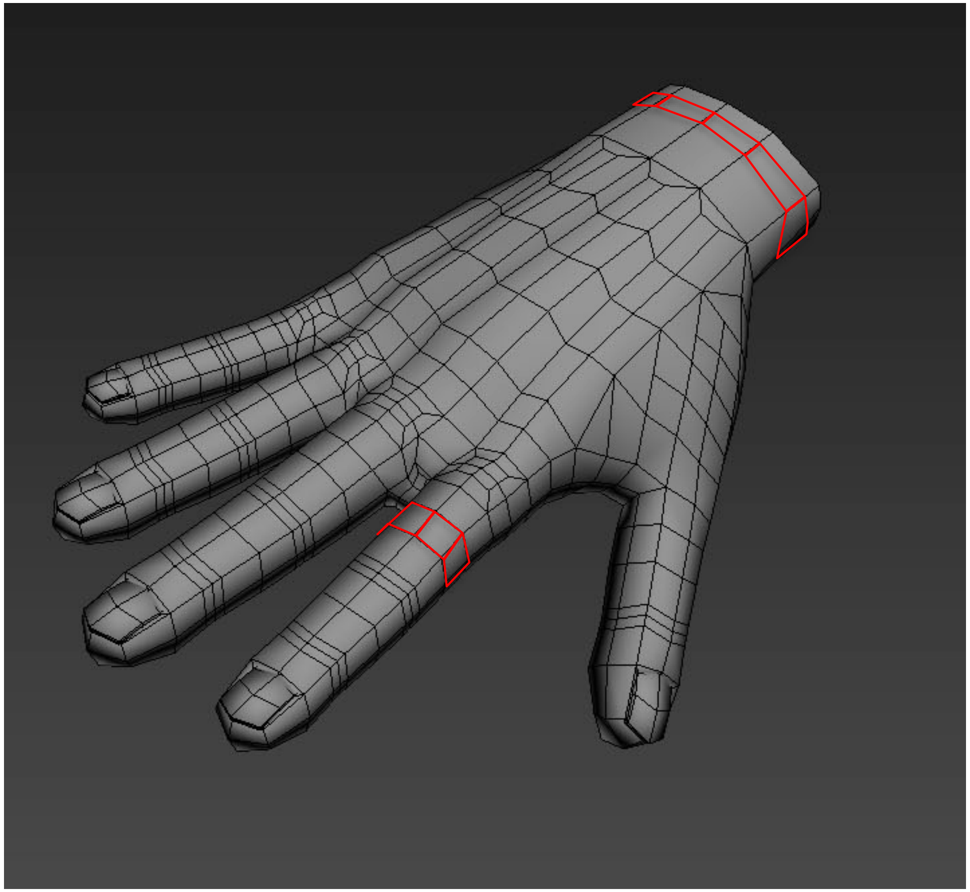


Naïve transmission scheme

Putting a whole signal segment in one packet is not ideal, because there is no way to recover information without resending



A whole segment of signal is lost



Compressive Wireless Pulse Sensing

Kevin Chen
Harnek Gulati
HT Kung
Surat Teerapittayanon

Signal Analysis

Wireless Data Transmission

Signal Acquisition