Clock Synchronization for Wireless Sensors at the Physical Layer

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Synchronized Wireless Sensors

Frequency synchronization opens many new opportunities:

Data aggregation over the air

Distributed Modulation

Distributed Compressive Sensing over the air

Why are today's wireless sensors not synchronized?

Wireless nodes have different clocks with slightly different frequencies.

AirShare transmits a reference clock over the air.

Challenge

Wireless nodes typically use a sine wave of 10-40 MHz for their reference clock.

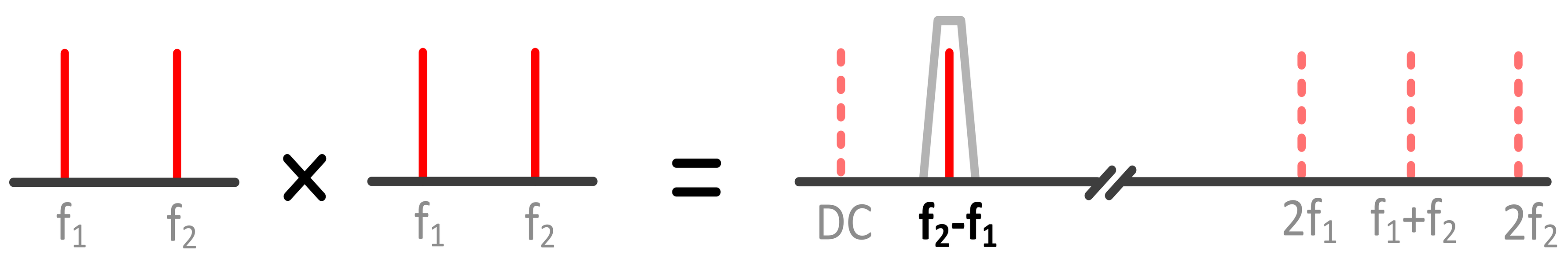
FCC forbids transmitting such a low-frequency signal for unlicensed use.

AirShare

Transmits two sine waves separated by the desired clock frequency.

Eg., for a clock of 10 MHz, send tones at 175 MHz and 185 MHz.

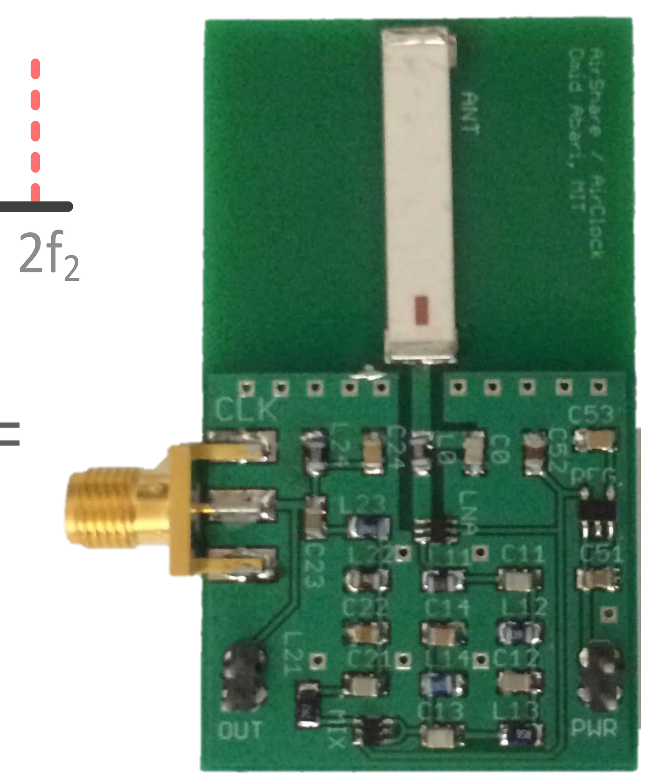
Each wireless node multiplies the received reference signal by itself and applies a band pass filter to extract the desired clock frequency.



$$(\cos(2\pi f_1 t)+\cos(2\pi f_2 t))\cdot(\cos(2\pi f_1 t)+\cos(2\pi f_2 t))=$$

$$\boldsymbol{\cos(2\pi(f_2-f_1)t)}+\cos(2\pi(f_2+f_1)t)+$$

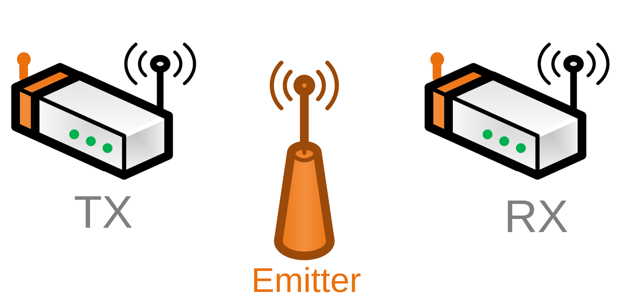
$$\frac{1}{2}\cos(2\pi(2f_1)t)+\frac{1}{2}\cos(2\pi(2f_2)t)+1$$

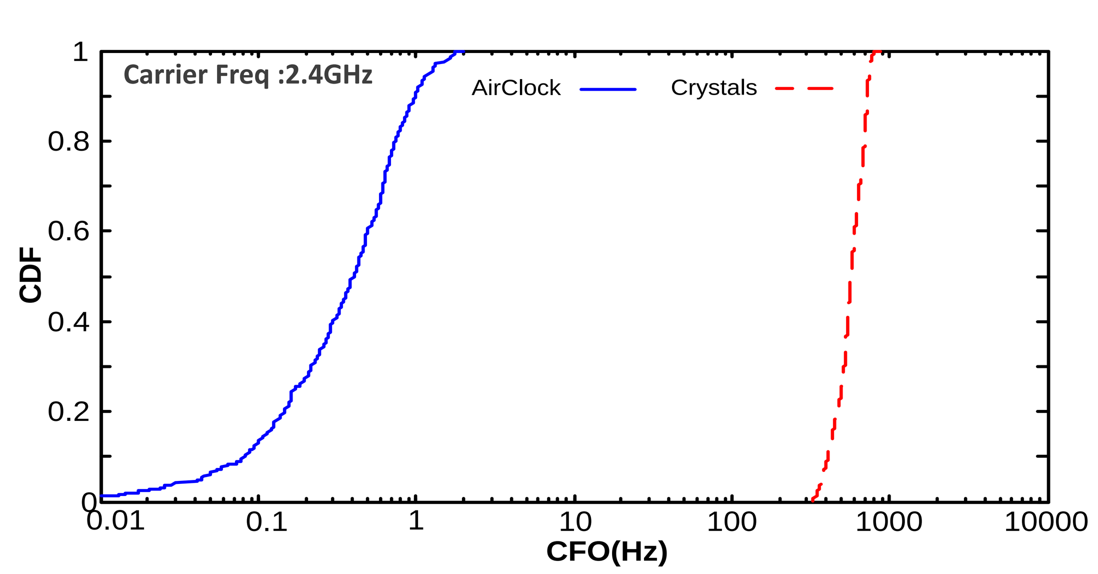


Microbenchmark

Coherent Transmission

TX and RX nodes use the same reference clock that they receive over the wireless medium.



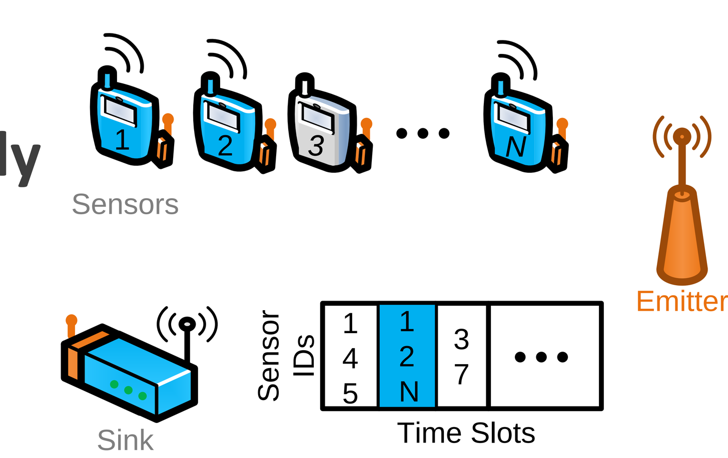


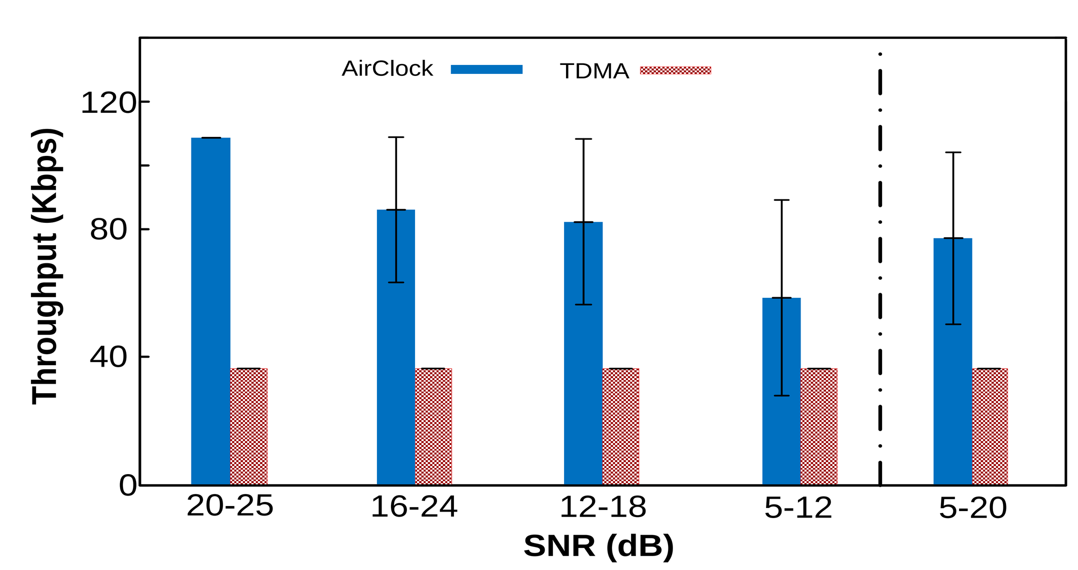
AirShare reduces the CFO by 300-400 ×

Application 1

Distributed Rate Adaptation

Sensors transmit simultaneously and create distributed codes over the air.



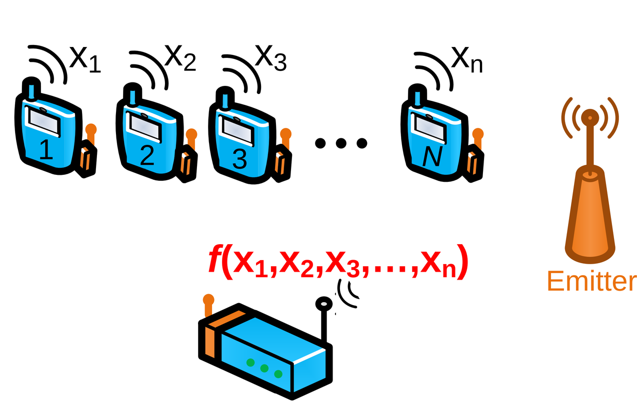


Throughput gains of 1.6–3 × over ZigBee for 6 sensors

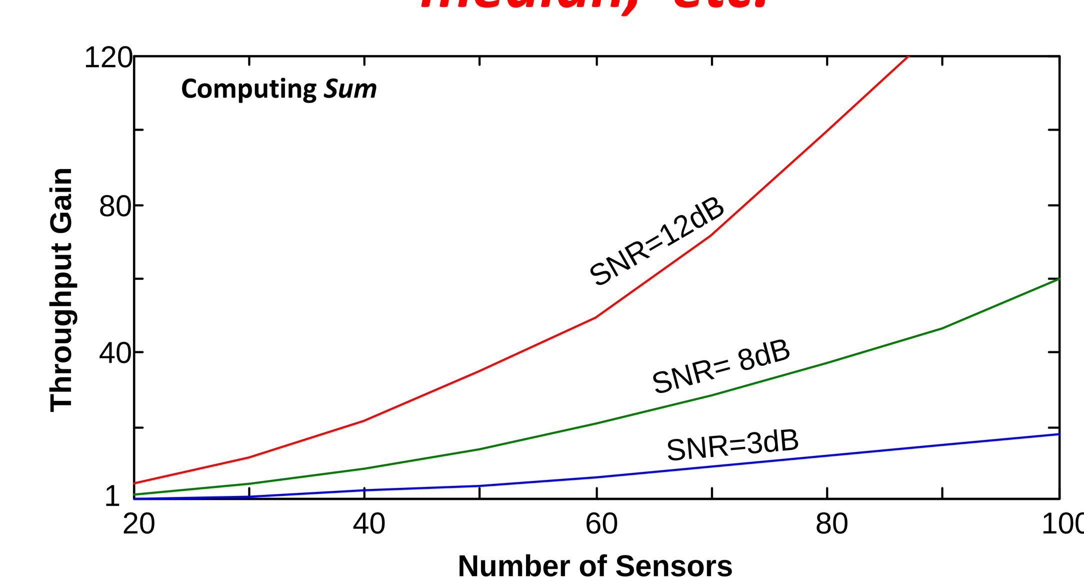
Application 2

Over-the-air Function Computation

Sensors transmit coherently so that sink directly receives the desired function value.



Many different functions: sum, mean, variance, max, min, median, etc.



Quadratic throughput gains