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.

AirClock 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.

AirClock

Transmits two sine waves separated by the desired clock frequency.

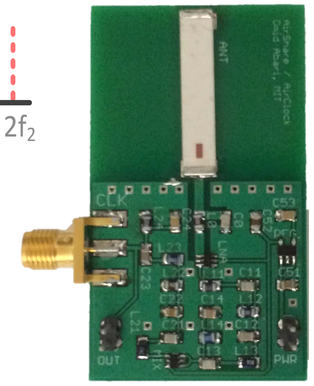
Eg., for a clock of 10 MHz, send tones at 175 MHz and 185 MHz.

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

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

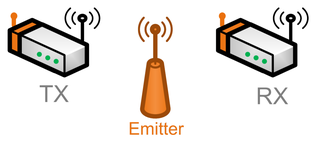
$$\boldsymbol{\cos(2\pi(f_2-f_1)t)}+\cos(2\pi(f_2+f_1)t)+$$

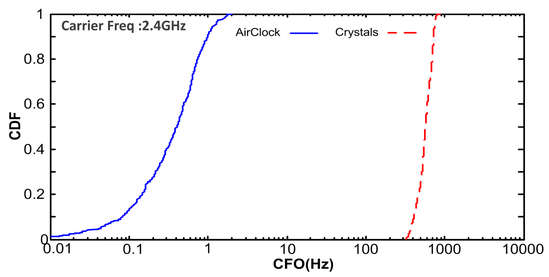
$$\frac{1}{2}\cos(2\pi(2f_1)t)+\frac{1}{2}\cos(2\pi(2f_2)t)+1$$



Microbenchmark
Coherent Transmission

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

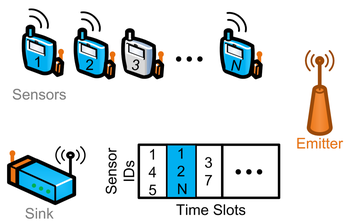


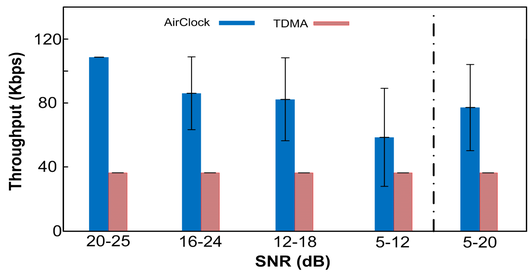


AirClock reduces the CFO by 300-400 ×

Application 1
Distributed Rate Adaptation

Sensors transmit simultaneously and create distributed codes over the air.

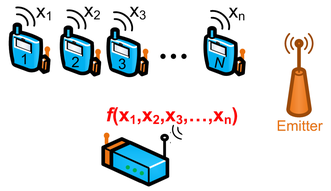




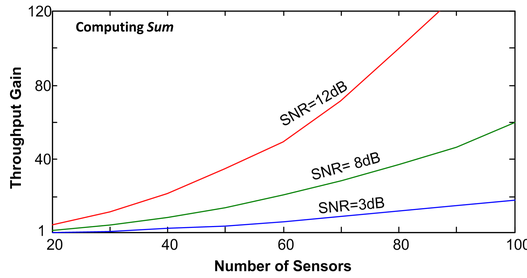
Throughput gains of 1.6–3 × over ZigBee for 6 sensors

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