# Combating Multi-camera Interference using Carrier Sensing

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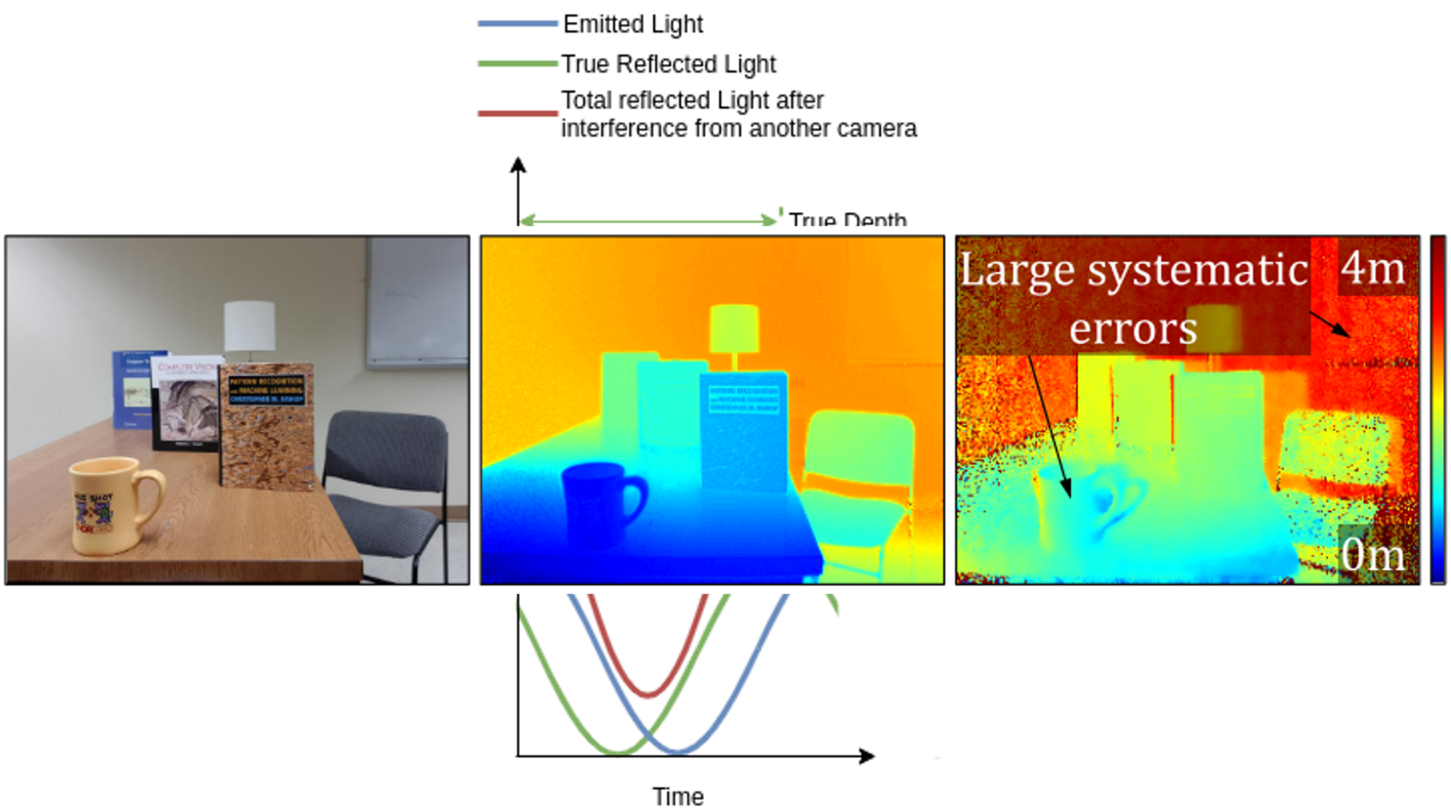
https://github.com/MCI/Combating MCI using Carrier Sensing

# Background: 3D Cameras

- 3D imaging is being used by vision and robotic systems to recover 3D scene geometry - important for technologies such as **autonomous transportation, augmented reality, and robot navigation.**
- **Active 3D Cameras** - use a programmable light source to emit coded light, which is used for scene depth estimation.
- Specifically, cameras that use the **Time-of-flight (ToF) principle** are proving useful for this purpose.
- As these cameras become **more ubiquitous**, they face the problem of interference.

# Problem Statement: Multi-camera Interference (MCI) in ToF Cameras

- The presence of interfering cameras, we face the issue of depth errors - due to **phase shifts**



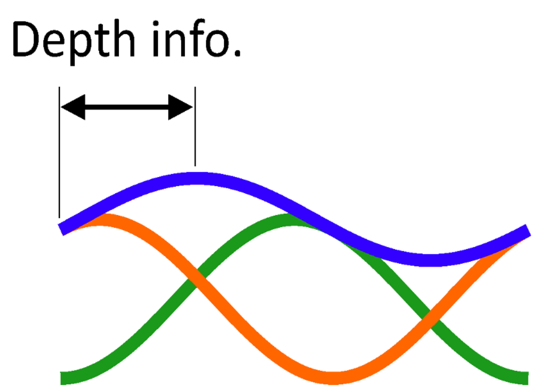

https://wisionlab.cs.wisc.edu/project/stochastictdma/

# Motivation: Utilize Wireless Protocols

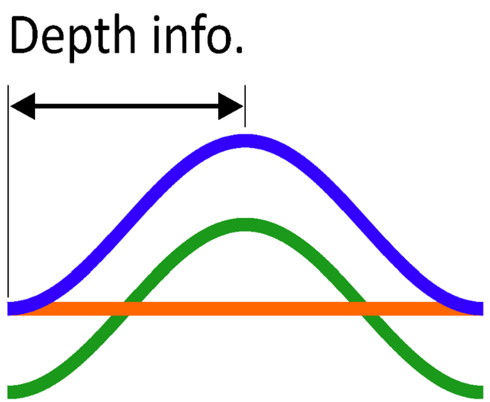
- Interference is a widely studied problem in wireless systems.
- In RF Systems, the transmitter sends the data which is carried by the channel to the receiver.
- In the MCI scenario, the transmitter sends a light beam, which *picks up* data from the object and reflects back to the receiver.
- Interference happens *at the receiver* in both cases!

# Prior Work: Different Modulation Frequencies

- Most conventional systems using ToF Cameras propose using different modulation frequencies for each camera.
- However, while this does reduce the interference in the oscillating part - it **fails to eliminate the interference in the constant part of the emitted light**.
- Leads to lower SNR and hence, does not solve the problem completely!



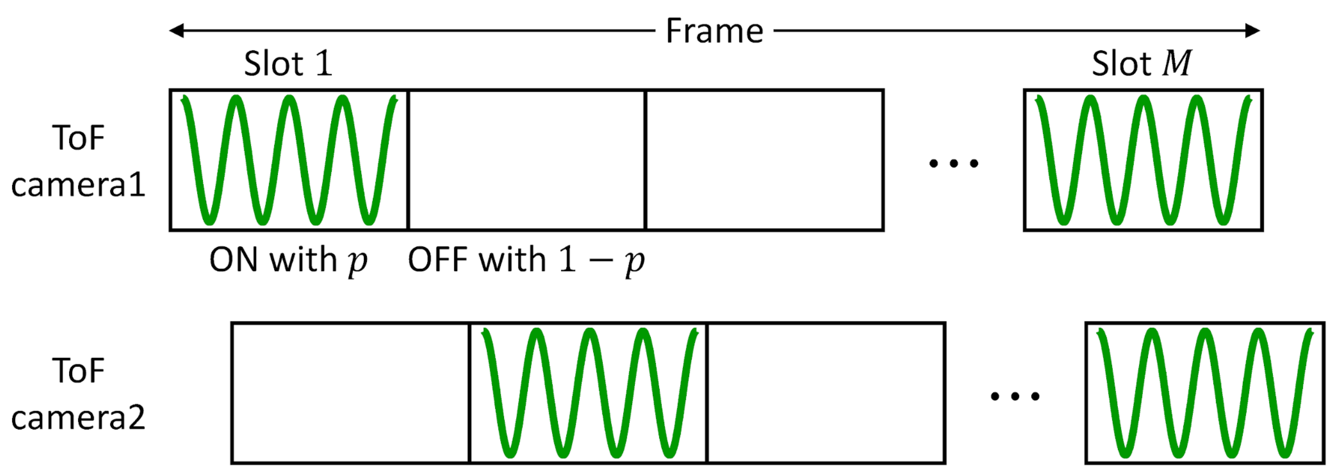

AC + DC interference




DC interference

# Prior Work: Stochastic Exposure Coding

- Similar to the Wireless Protocol **Slotted Aloha**.
- Instead of keeping the emitter and sensor 'on' at all times, do a probabilistic switch on-off procedure to reduce the chances of collisions.

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# Prior Work: Stochastic Exposure Coding

- Similar to the Wireless Protocol **Slotted Aloha**.
- Instead of keeping the emitter and sensor 'on' at all times, do a probabilistic switch on-off procedure to reduce the chances of collisions.
- *There ain't no free lunch!!!*
  - Increase in the Total Integration Time
  - Decrease in the Effective Exposure Time
- The points above lead to the following constraints:
  - Increase in Source Power Amplification - to counter the decrease in effective exposure time.
  - Choice of the Slot ON probability

# Prior Work: Stochastic Exposure Coding

- Similar to the Wireless Protocol **Slotted Aloha**.
- Instead of keeping the emitter and sensor ‘on’ at all times, do a probabilistic switch on-off procedure to reduce the chances of collisions.
- **Handling Collisions:** Post receive mechanism - if the received light intensity in a slot is higher than the “usual”, declare it a clashed slot.

# Intervention: Use Carrier Sensing

- **Observation:**
  - The current approach of stochastic slots and then do collision detection, is a *passive approach.* A more *active approach can be used.*
  - Drawing inspiration from wireless CSMA-CA protocol, we *avoid* collisions instead of *detecting* them.
- Additional Benefit: We **may not suffer** from the Hidden Terminal/Exposed Terminal problems in the MCI scenario.
  - Occurs widely in wireless systems because transmitter is *unaware of the channel state* at receiver.
  - In MCI, transmitter-receiver are co-located!
- **Result:** We still use multiple slots in the total integration time, but the camera only emits light *post sensing the channel*.

# Intervention: Algorithm

```
At each slot
        Sense the channel to see if it is busy
        If channel is busy
                Defer the current slot
        Else
                Transmit light and receive from the object post reflection
                Employ collision detection to check if no camera interfered
Use the non clashed slots for depth estimation
```

# Results: Simulation

- We evaluate the carrier sensing protocol in an MCI environment, where other cameras **may randomly switch on-off with some probability** in the entire duration.
- Comparison Baselines:
  - PN (Pseudonoise): Uses non-sinusoid modulation and demodulation functions. Proposed for early ToF cameras in 2007.
  - ACO (AC Orthogonal): Using orthogonal frequencies for the interfering cameras.
  - SEC (Stochastic Exposure Coding): Makes use of a stochastic TDMA protocol
  - CMB: Combined ACO and SEC
  - CSMA: Intervention to use a-priori carrier sensing

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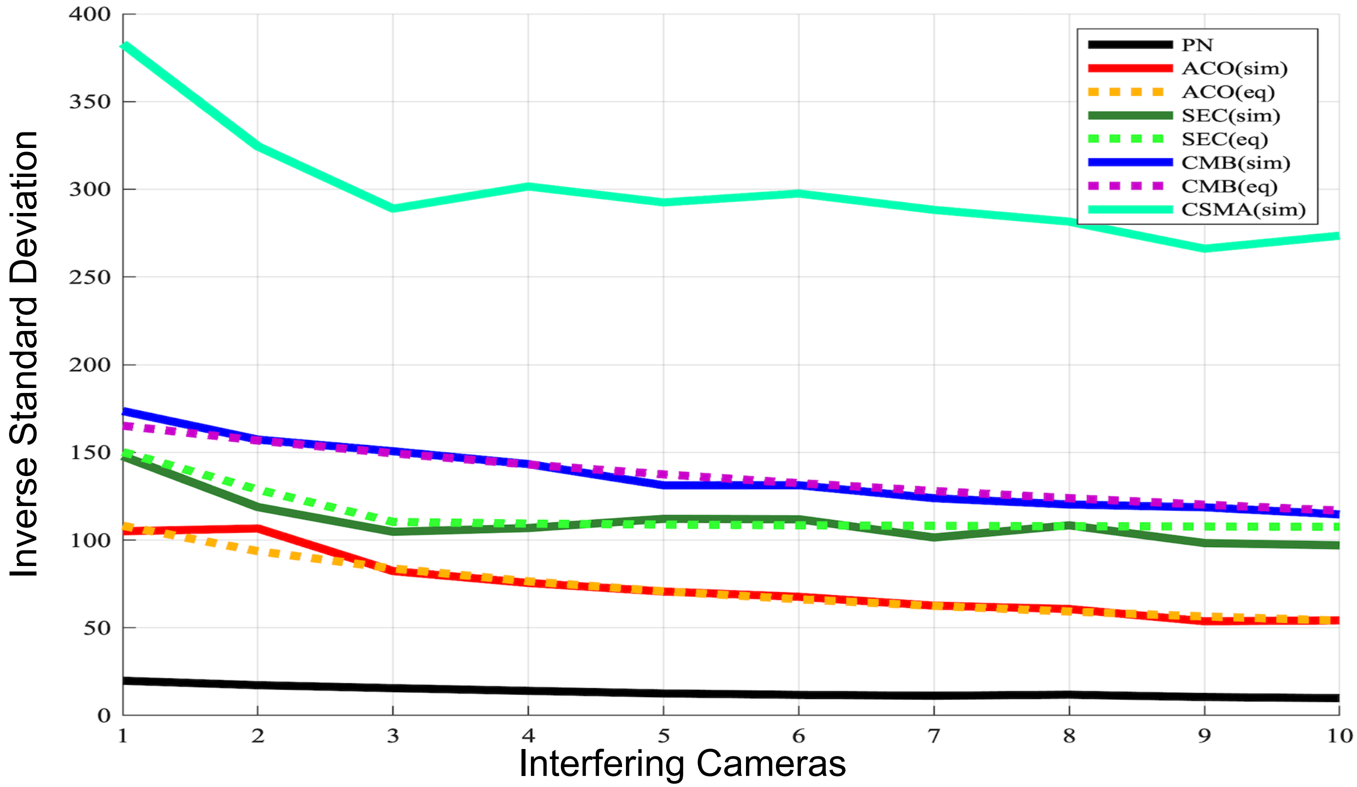
- Following results are for CSMA approach using the **same Power Amplification as SEC**



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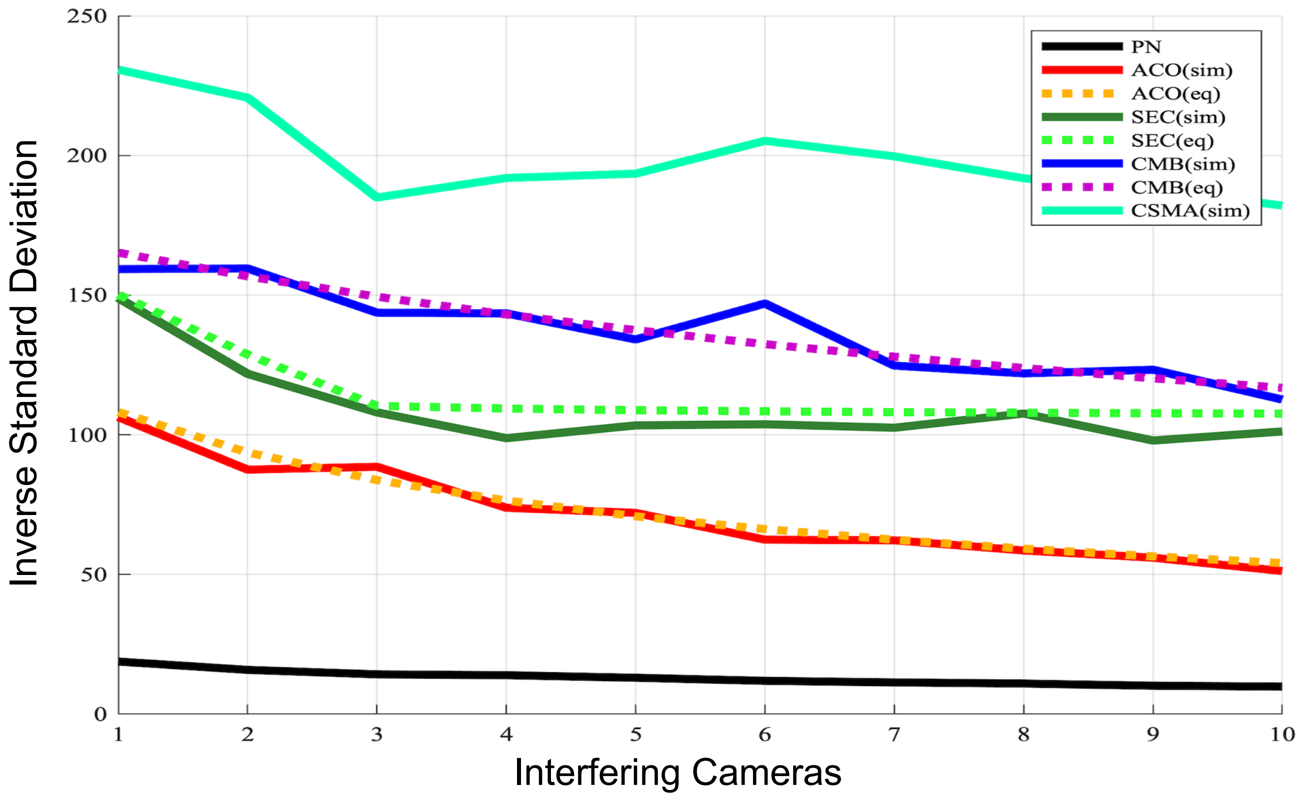
- Following results are for CSMA approach using the **half Power Amplification as SEC**



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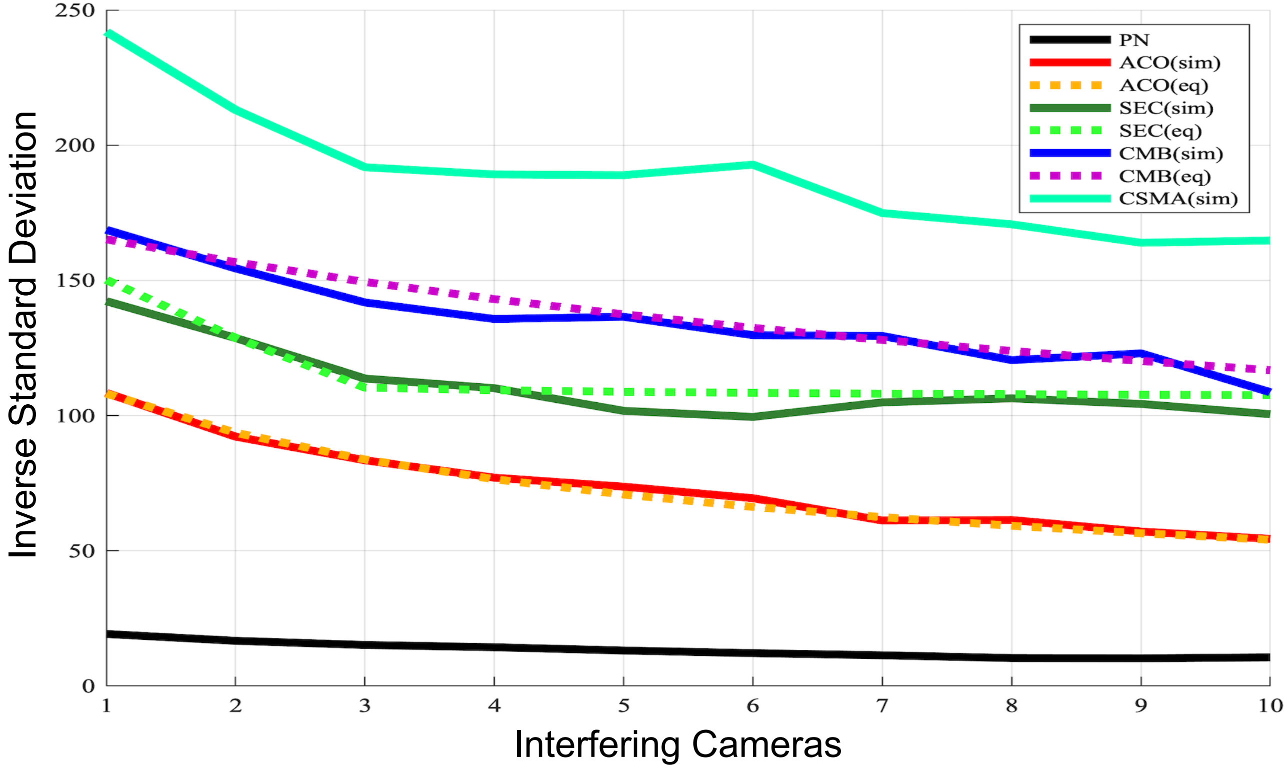
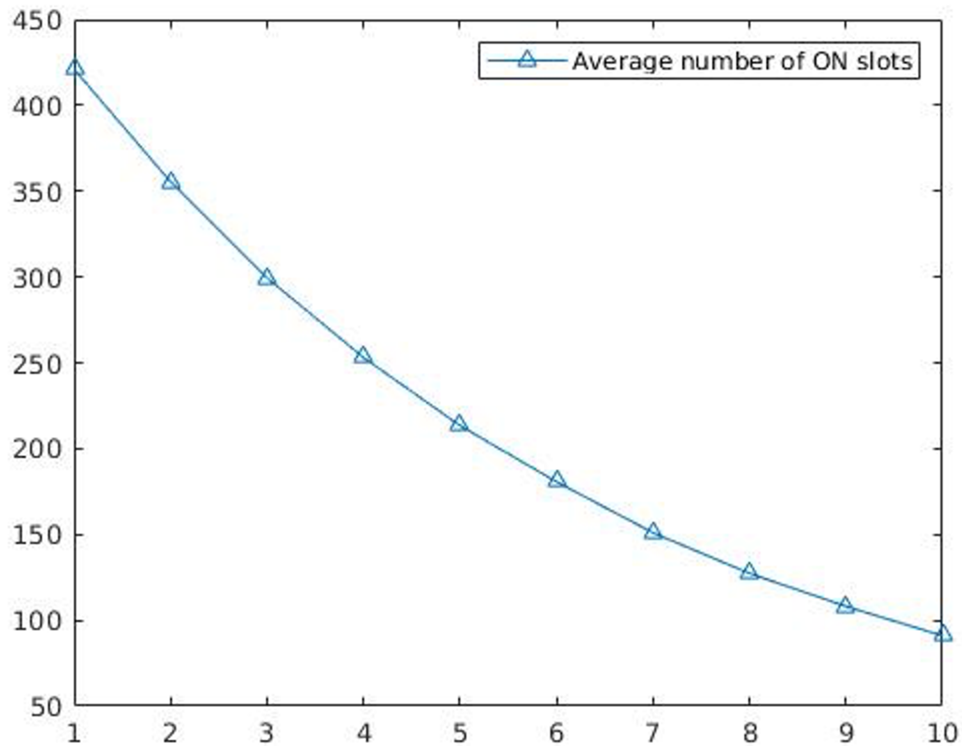
  - CMB: Combined ACO and SEC
  - CSMA: Intervention to use a-priori carrier sensing
- Following results are for CSMA approach using the **half Power Amplification as SEC** and **10% increase in probability p_CMB**



# Results: Simulation

- The average number of ON slots for the camera following the CSMA protocol, in an MCI environment of interfering cameras switching on and off in each slot with a probability:
  - Total slots in the integration time = 500

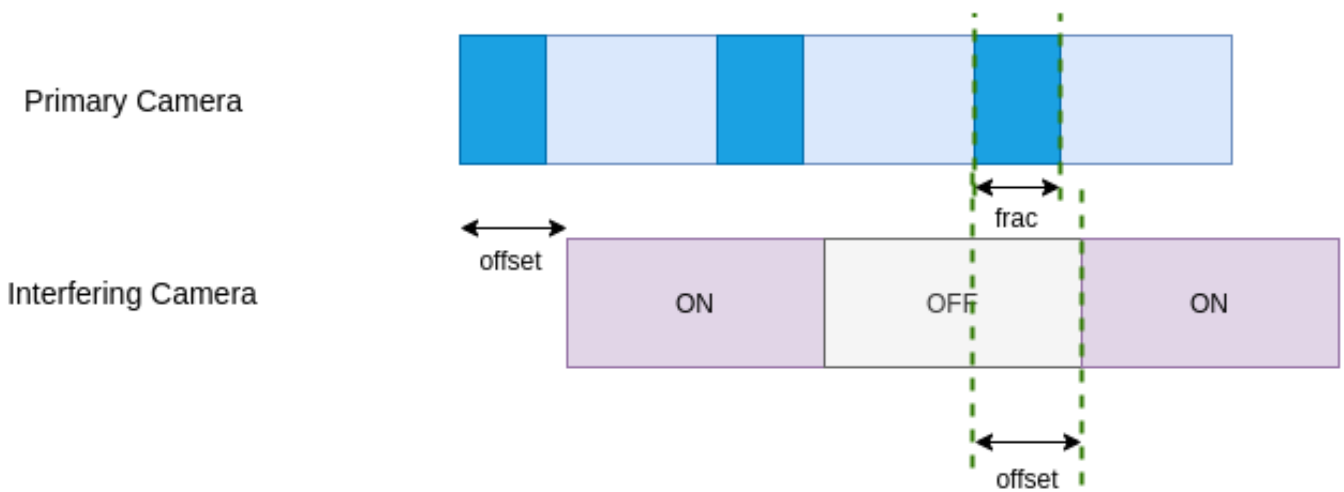


# Simulating Real Time Scenarios

- The previous algorithm does *carrier sensing* and *depth estimation* in the same slot.
- In reality, if we employ carrier sensing in every slot, the duration for depth estimation decreases.
- To account for this change, we introduce a new parameter – ‘frac’, which determines the fraction of each slot spent in collision detection.

# Relationship between Frac and Interference – Case 1

```
If offset > 0 (left case):
        slot[N] = ! intSlot[N-1]
        if offset < frac:
                slot[N] = ! intSlot[N]
        else:
                intAmt[N] = (1 - offset)
```

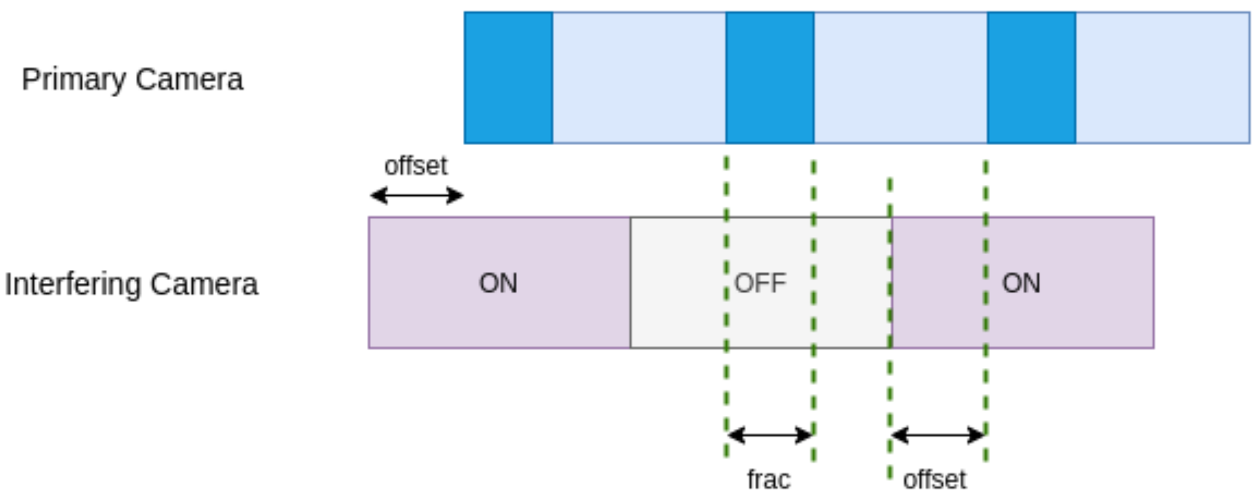



slot[.] is an array with values 0/1 depicting whether nth slot of primary camera is ON or OFF.

intAmt[.] holds the total observed interference for nth slot for the primary camera.

# Relationship between Frac and Interference – Case 2

```
If offset < 0 (right case):
        slot[N] = ! intSlot[N]
        if offset < 1 - frac:
                slot[N] = ! intSlot[N+1]
        else:
                intAmt[N] = abs(offset)
```

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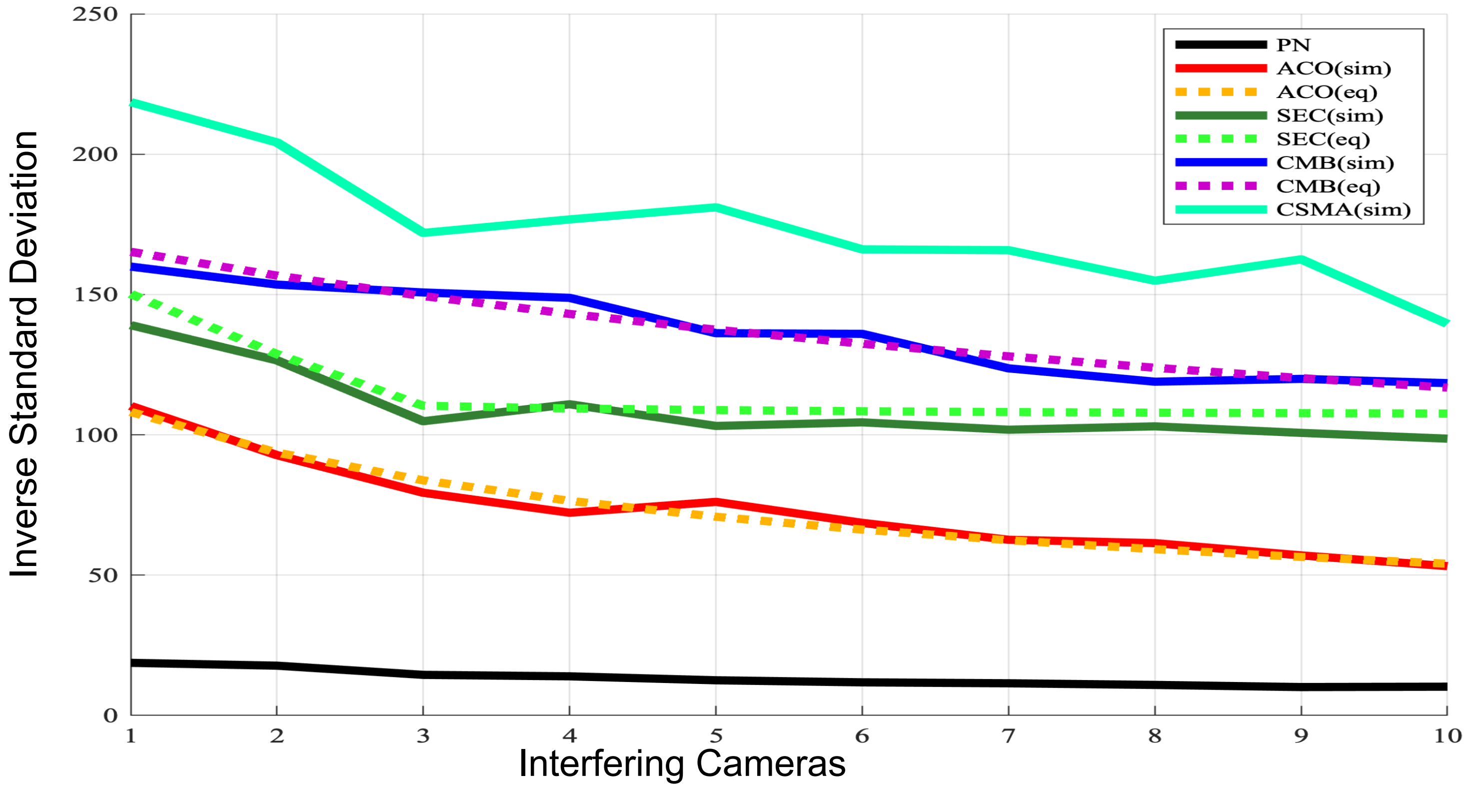
- Following results are for CSMA approach using the **frac = 0.1**, **half Power Amplification as SEC, 10% increase in probability p_CMB**



# Results: Simulation

- Comparison Baselines:
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  - CMB: Combined ACO and SEC
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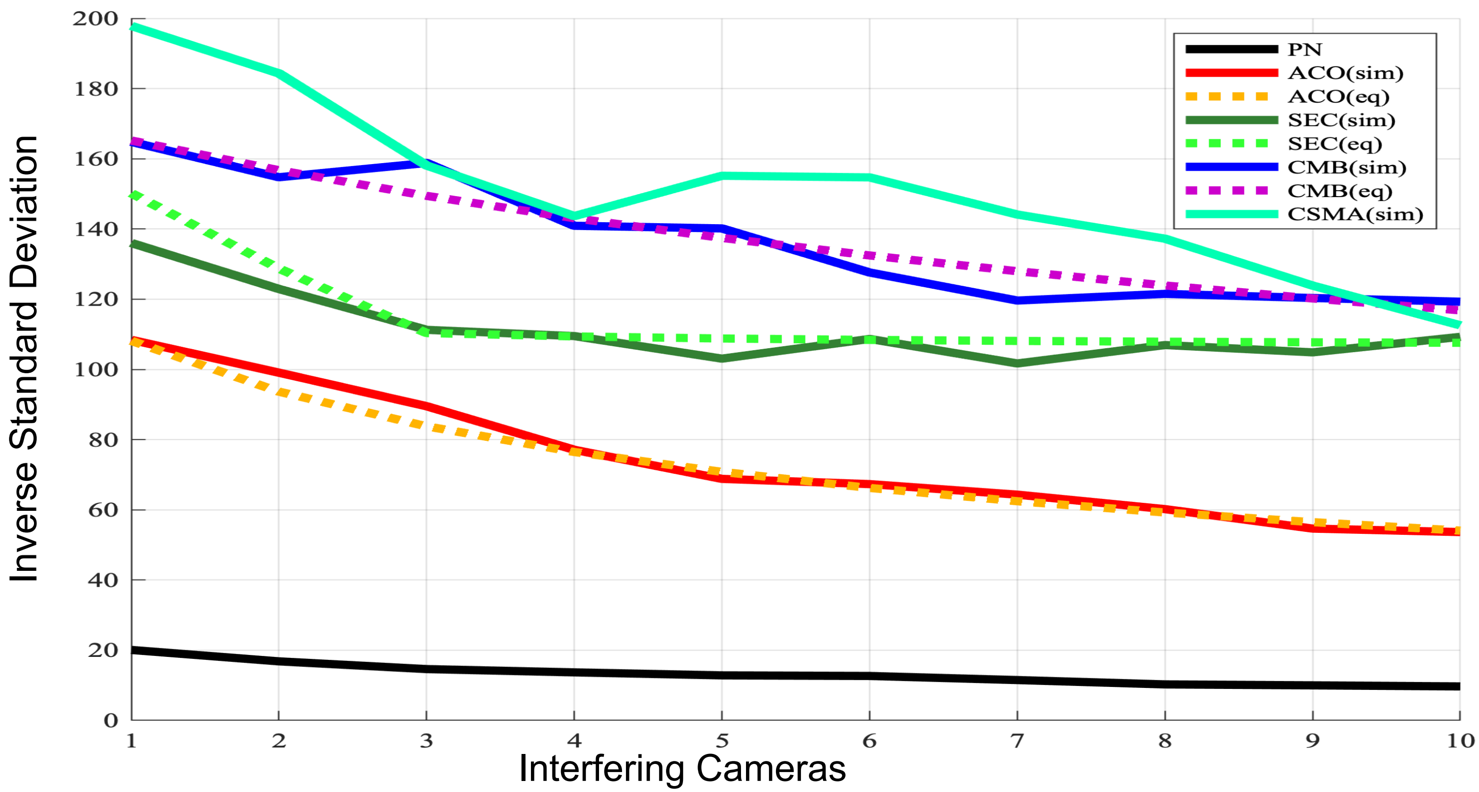
- Following results are for CSMA approach using the **frac = 0.3**, **half Power Amplification as SEC, 10% increase in probability p_CMB**



# Results: Simulation

- Comparison Baselines:
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  - CMB: Combined ACO and SEC
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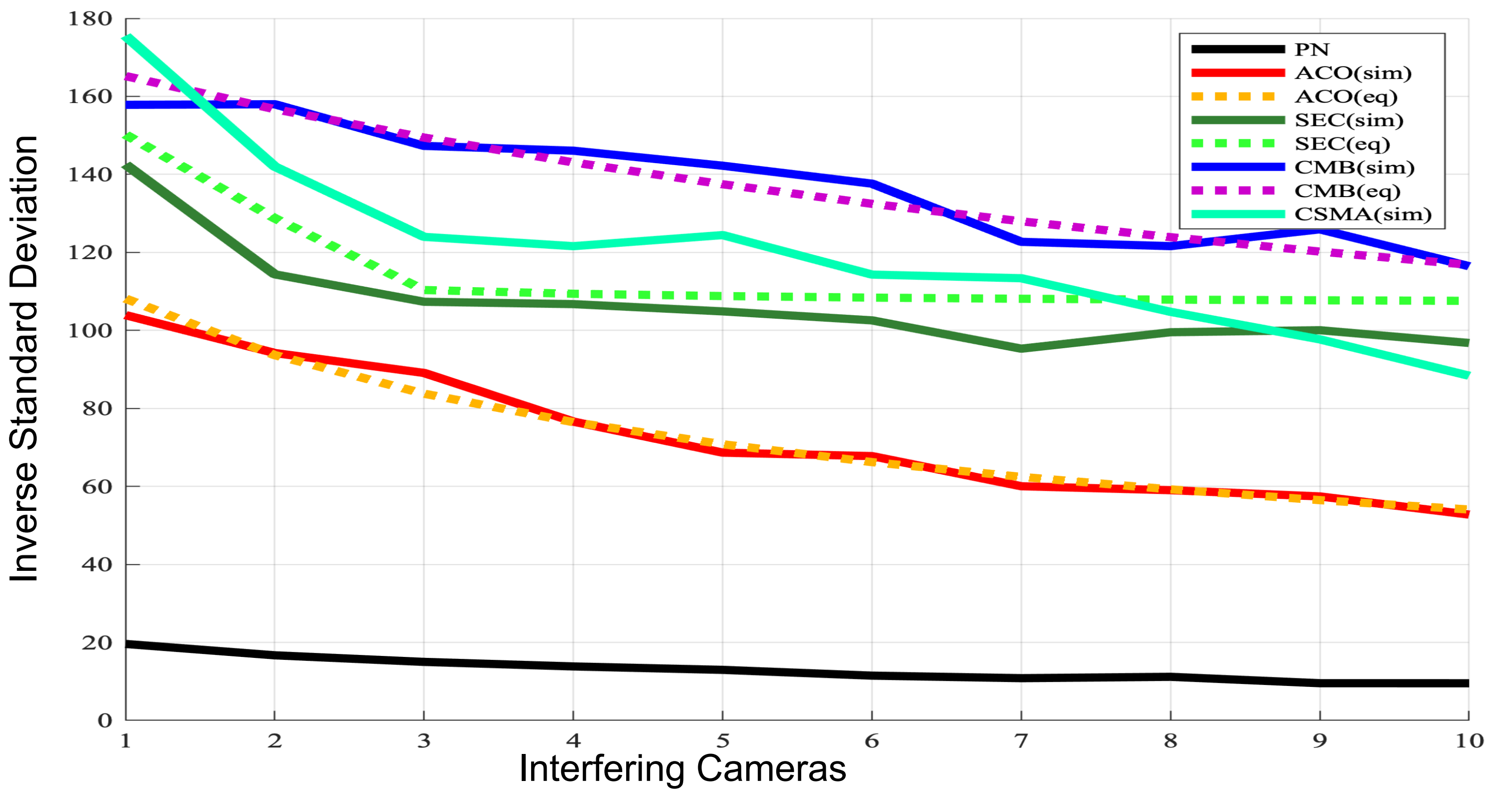
- Following results are for CSMA approach using the **frac = 0.5**, **half Power Amplification as SEC, 10% increase in probability p_CMB**



# Results: Simulation

- Comparison Baselines:
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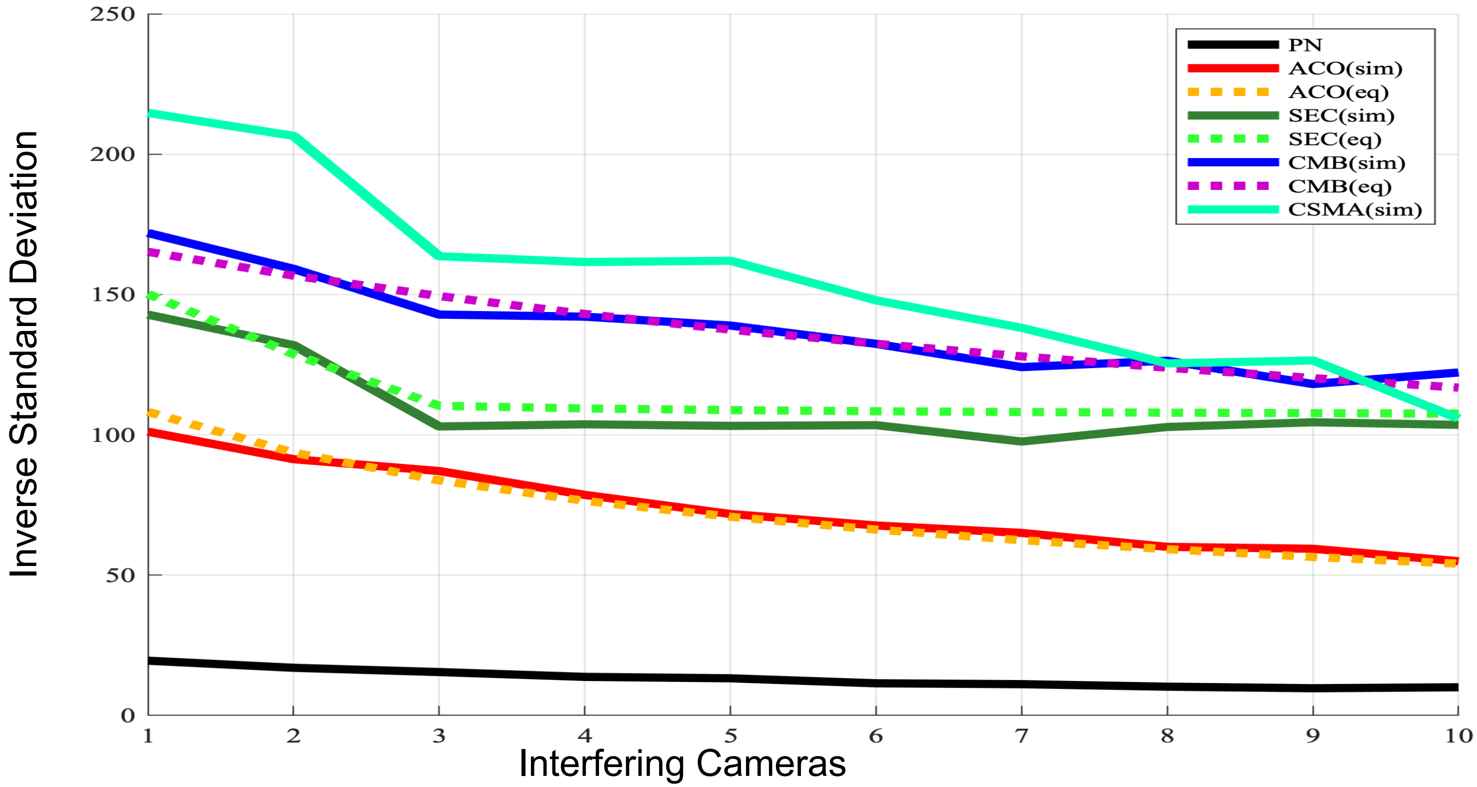
  - SEC (Stochastic Exposure Coding): Makes use of a stochastic TDMA protocol
  - CMB: Combined ACO and SEC
  - CSMA: Intervention to use a-priori carrier sensing
- Following results are for CSMA approach using the **frac = 0.5**, **75% Power Amplification as SEC, 10% increase in probability p_CMB**



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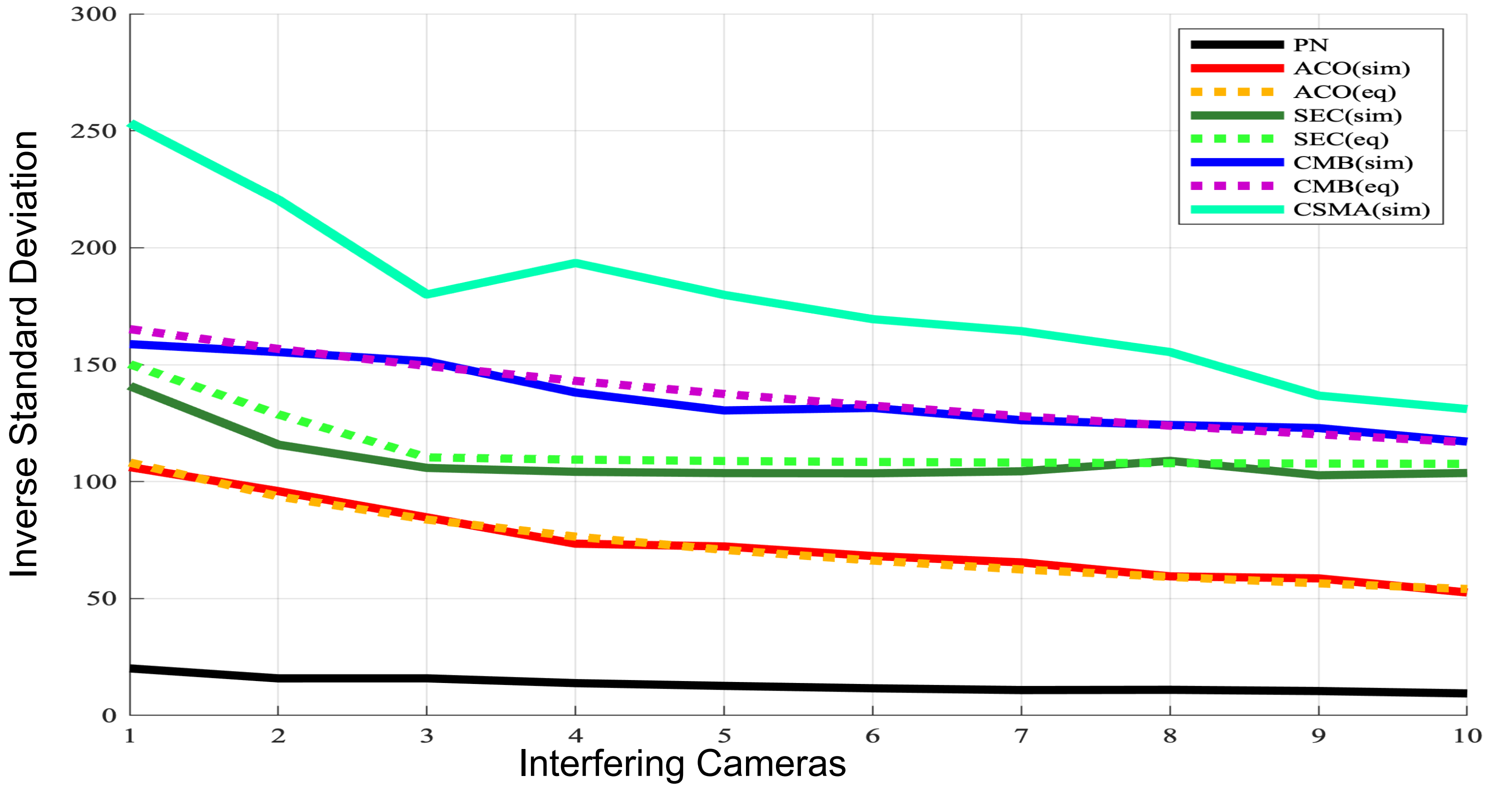

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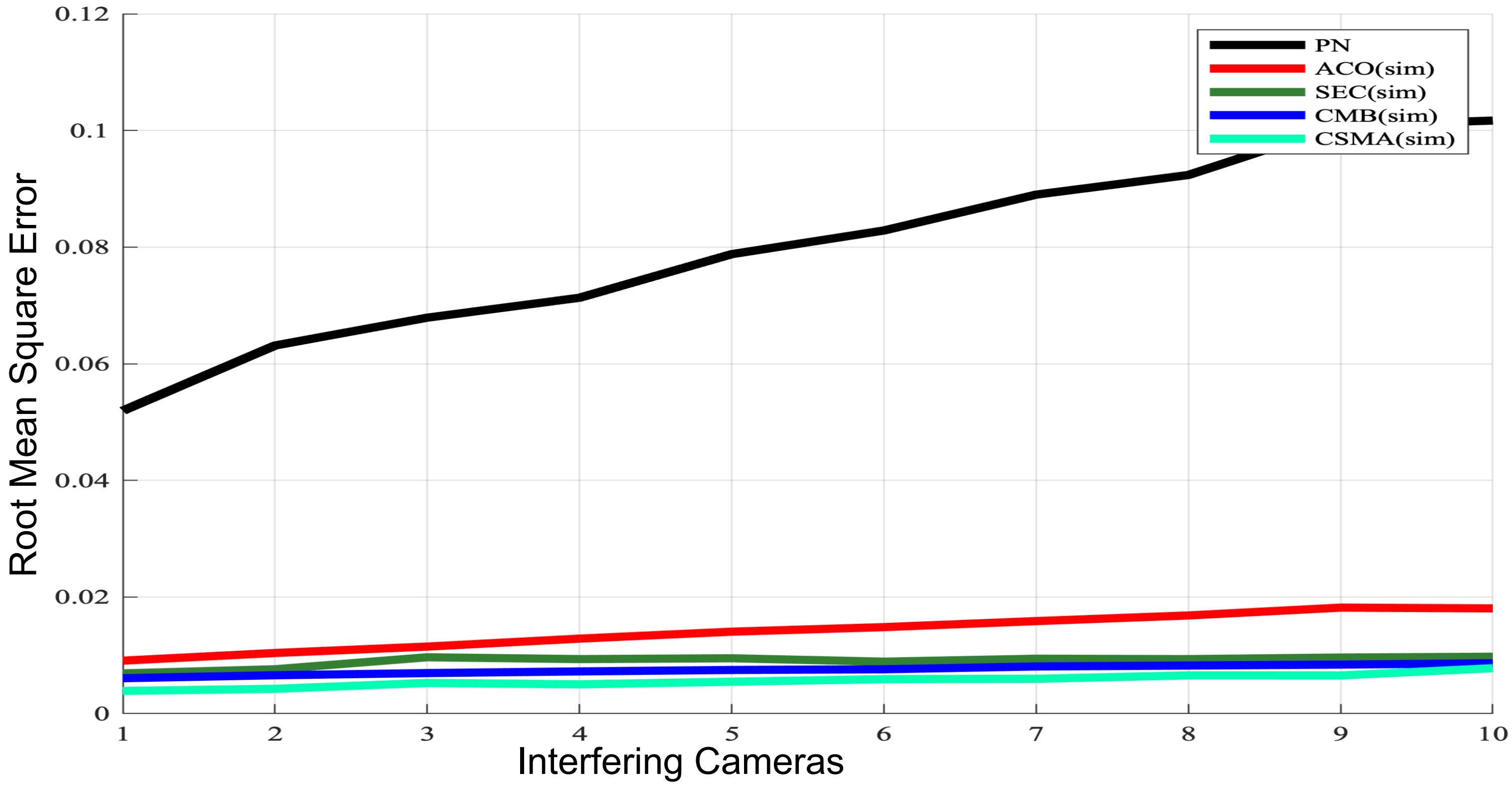

# Conclusion

- CSMA approach does give a better performance over SEC under the same experimental setting.
- There is a direct correlation between time spent in collision detection and the accuracy of estimated depth.
- Reduction in depth estimation time can be compensated by increasing the power amplification.

# Next Steps

- Include power amplification needed for carrier sensing in the total power calculation.
- Theoretical bounds for the peak power amplification for the carrier sensing protocol.
- Simulate a real world setting where each interfering camera can follow a different protocol.

Thank you !

Questions ?