Combating Multi-camera Interference using Carrier Sensing

DIVYANSHU SAXENA

ABISHEK KUMAR

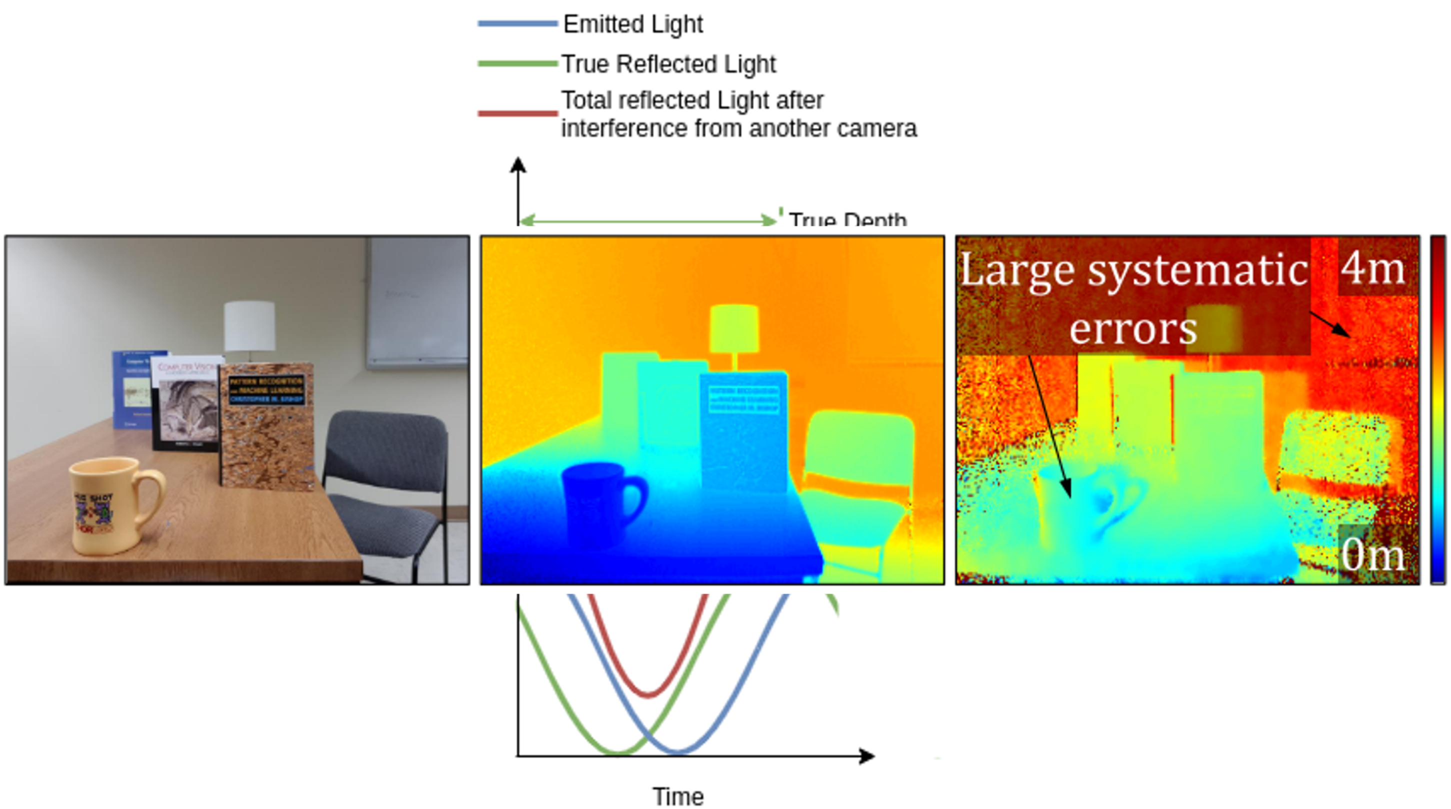
https://github.com/MCI/Combating_MCI_Using_CSMA.pptx

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**



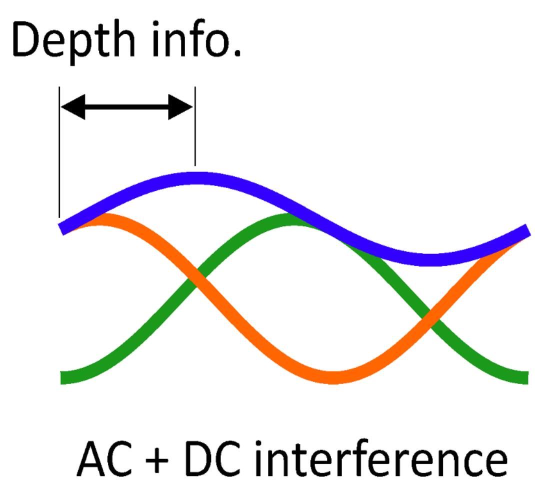
https://wisionlab.cs.wisc.edu/project/stochastictdma/

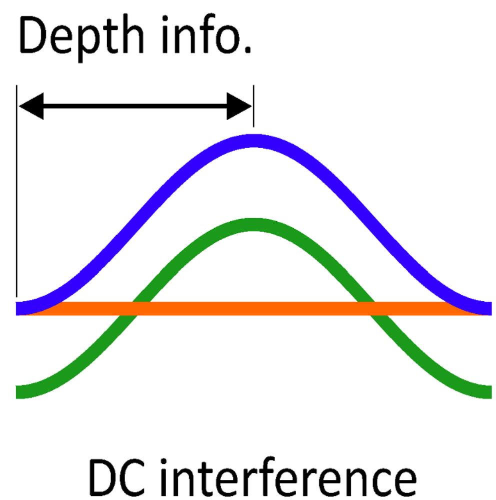
Motivation: Utilize Wireless Protocols

- 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

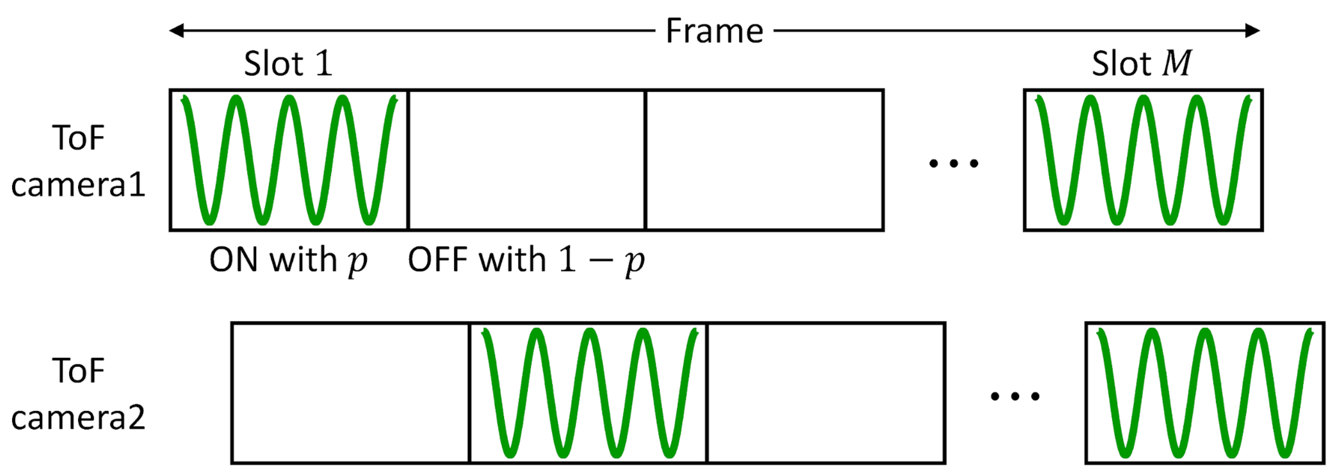
- Most conventional systems using ToF Cameras propose using different modulation frequencies for each camera.
- However, while this does reduce the interference in the oscillating part - it **fails to eliminate the interference in the constant part of the emitted light**.
- Leads to lower SNR and hence,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





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.



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

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

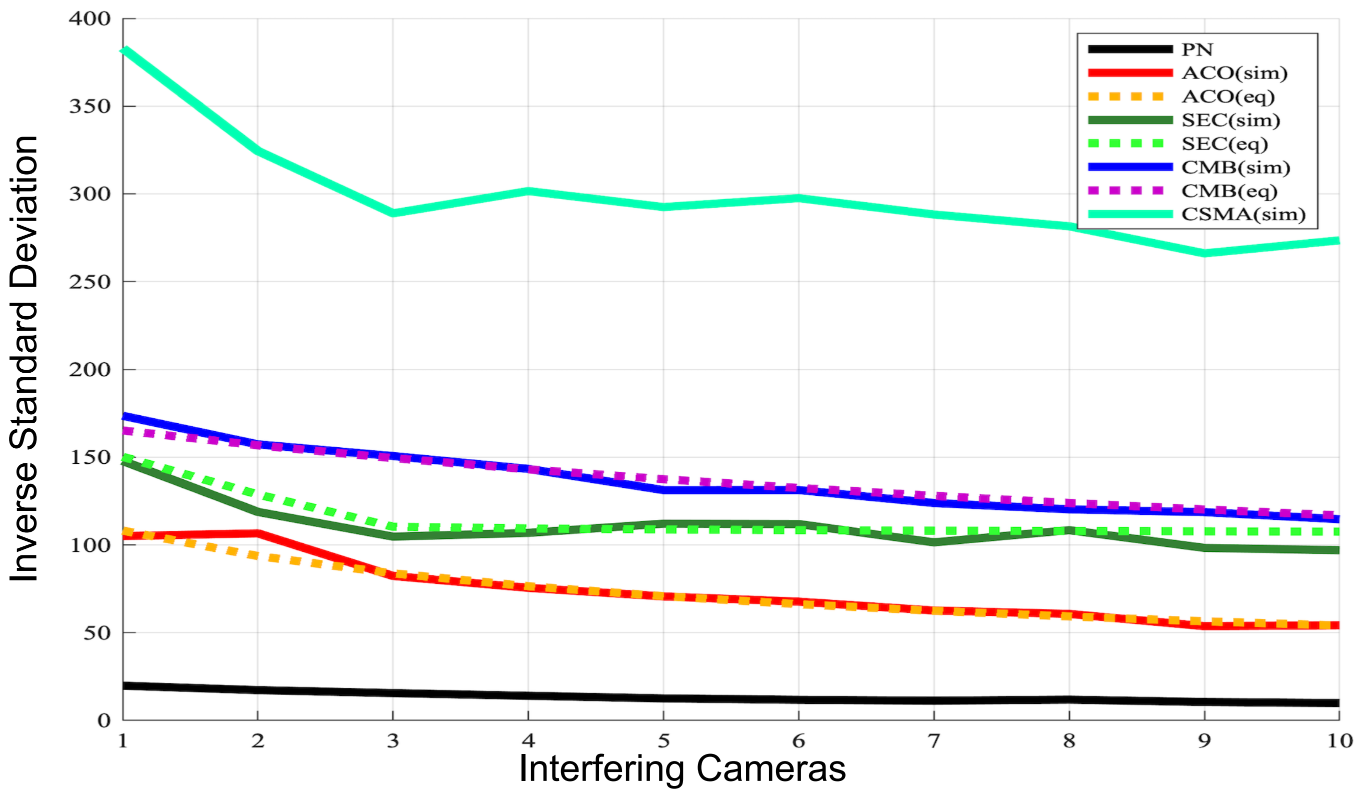
```
At each slot
    Sense the channel to see if it is busy
    If channel is busy
        Defer the current slot
    Else
        Transmit light and receive from the object post reflection
        Employ collision detection to check if no camera interfered
Use the non clashed slots for depth estimation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

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

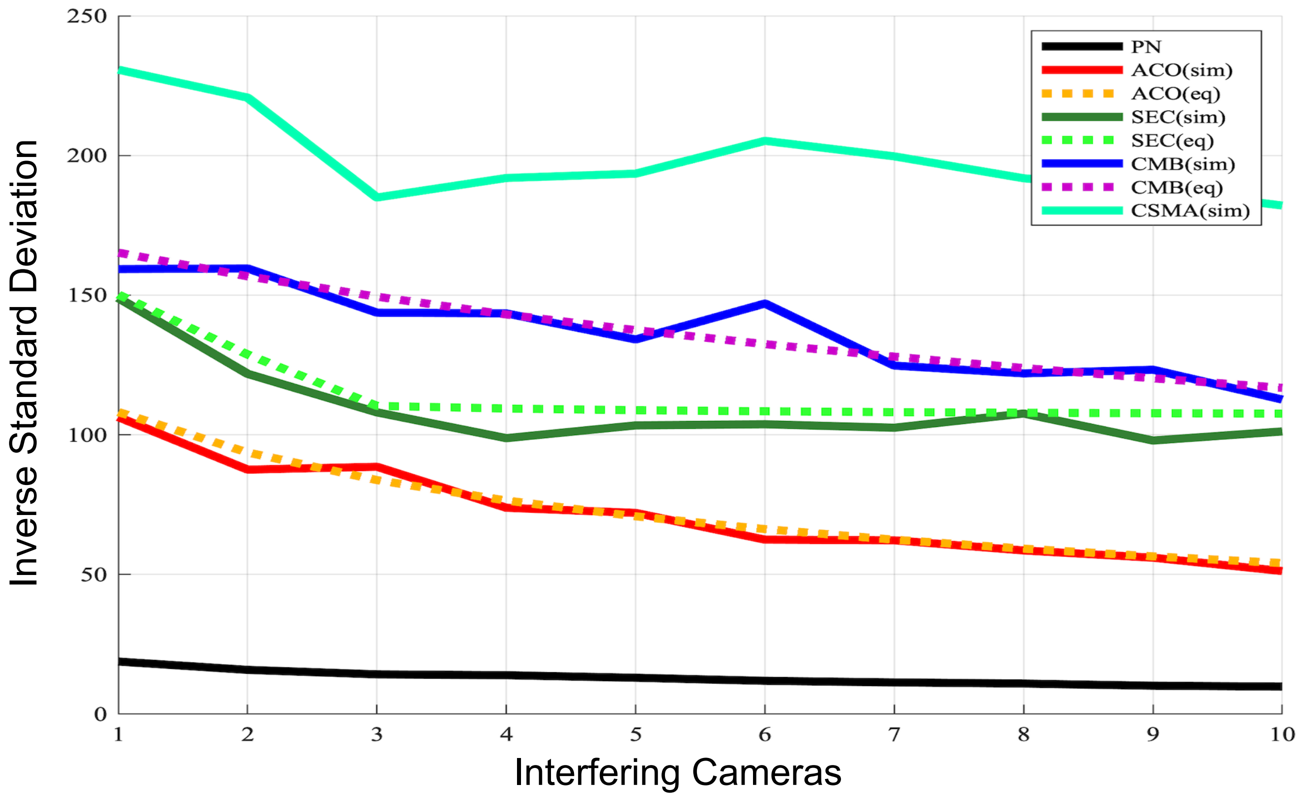
Results: Simulation

- Comparison Baselines:
  - PN (Pseudonoise): Uses non-sinusoid modulation and demodulation functions.
  - 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
- Following results are for CSMA approach using the **same Power Amplification as SEC**



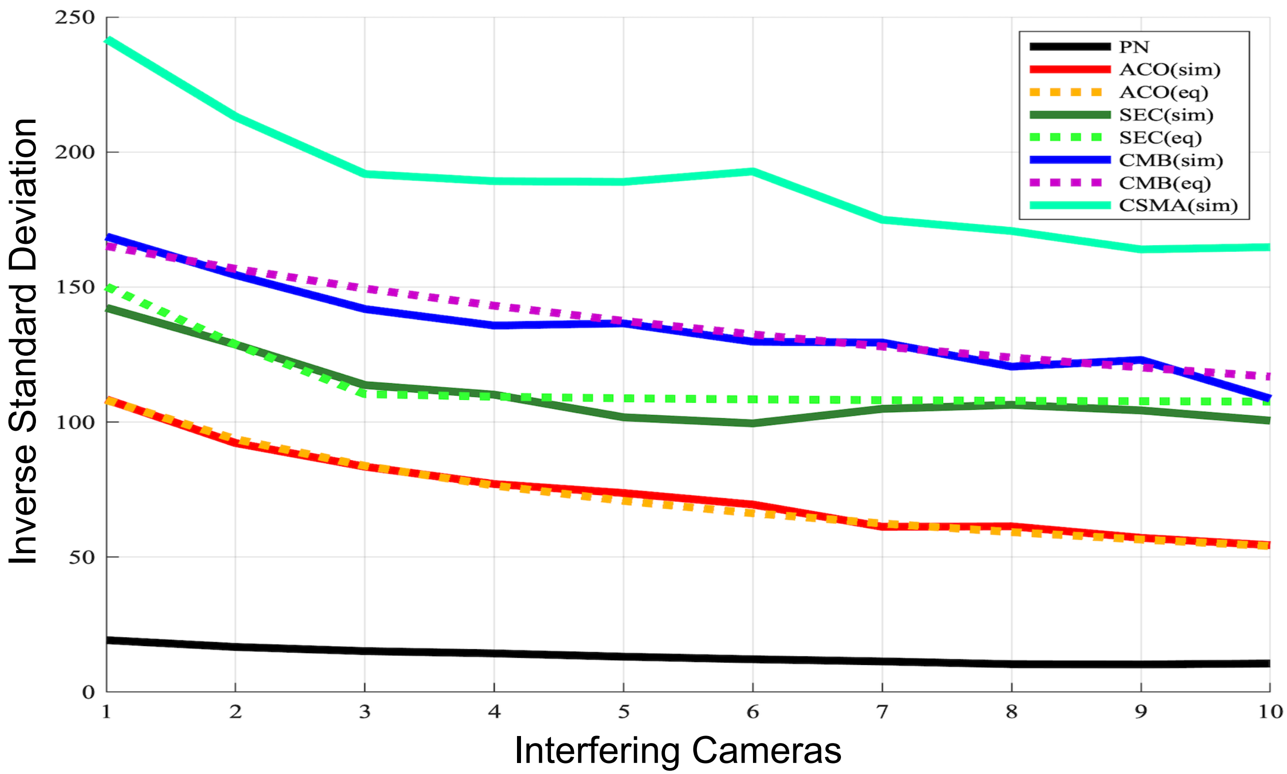
Results: Simulation

- Comparison Baselines:
  - PN (Pseudonoise): Uses non-sinusoid modulation and demodulation functions.
  - 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
- Following results are for CSMA approach using the **half Power Amplification as SEC**



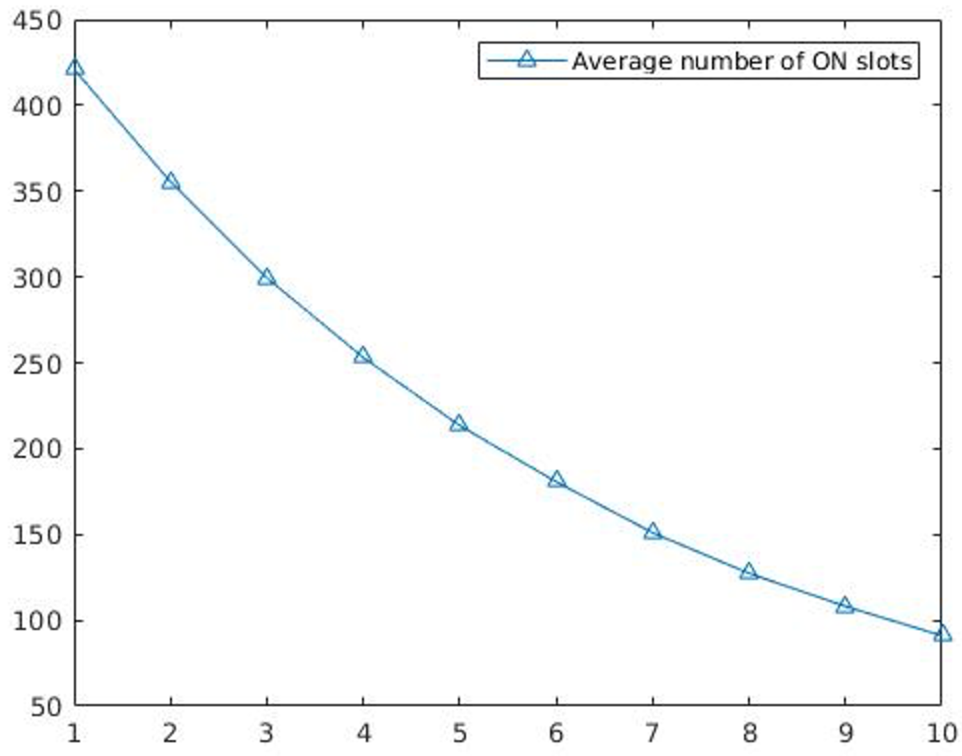
Results: Simulation

- Comparison Baselines:
  - PN (Pseudonoise): Uses non-sinusoid modulation and demodulation functions.
  - 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
- 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



Next Steps

- Evaluate under more circumstances of power amplifications and ON probabilities of interfering cameras.
- Simulate a real world setting where each interfering camera can follow a different protocol.
- Theoretical bounds for the peak power amplification for the carrier sensing protocol.
- Verify feasibility of slot durations in real ToF cameras.