Collaborative Processing in Sensor Networ

Lecture 5 - Visual Coverage

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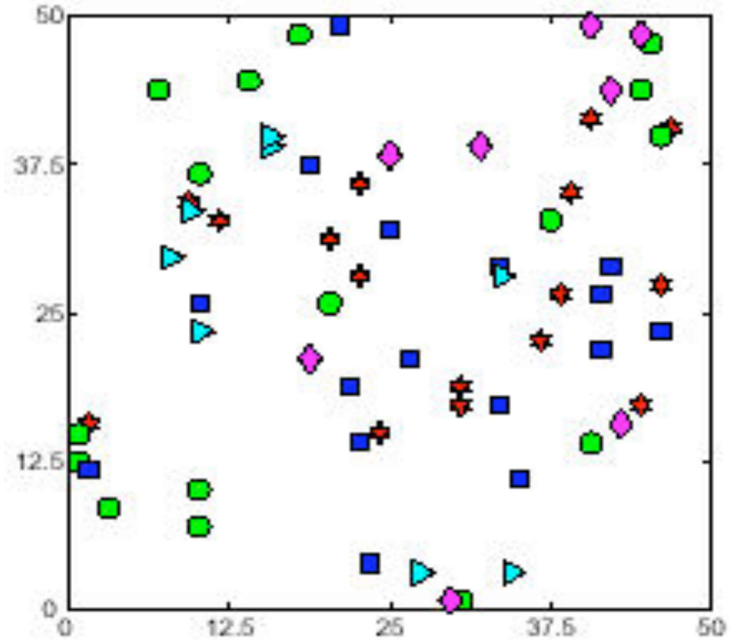
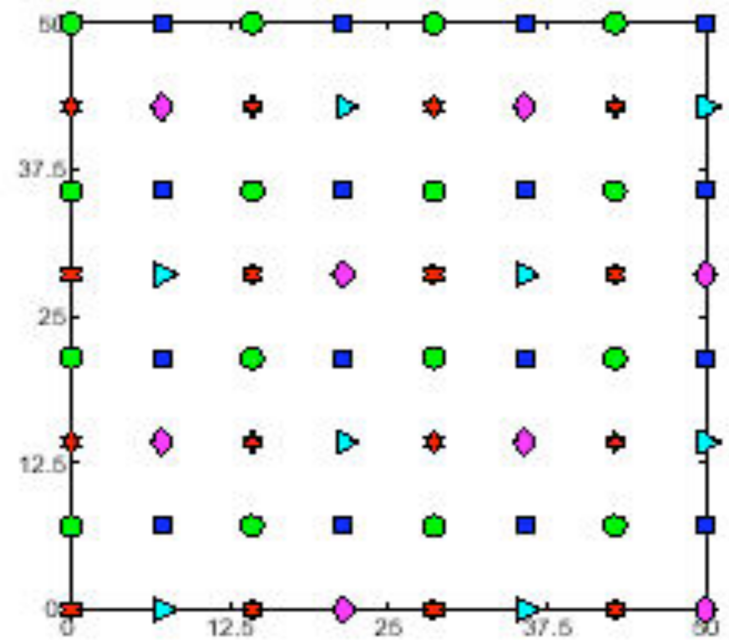
Research Focus - Recap

- Develop energy-efficient collaborative processing algorithms with fault tolerance in sensor networks
  - Where to perform collaboration?
    - Computing paradigms
  - Who should participate in the collaboration?
    - Reactive clustering protocols
    - Sensor selection protocols
  - How to conduct collaboration?
    - In-network processing
    - Self deployment <--> Coverage

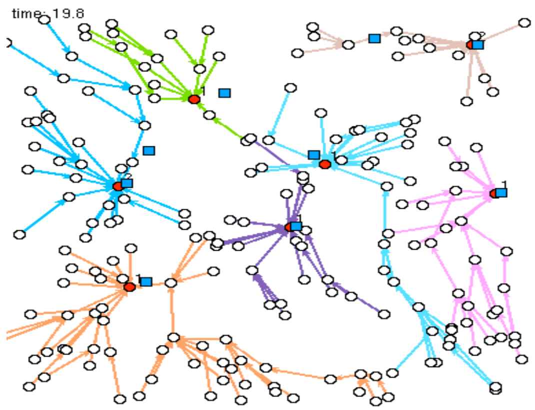
Coverage vs. Deployment





Visual Sensor Networks

Orite.com



Geometry.Stanford.edu

Epfl.cl

Visual sensor

Visual sensing, computing, and wireless communication.

Sensor networks

A large population of nodes

Visual sensor networks

Collaborative visual computing

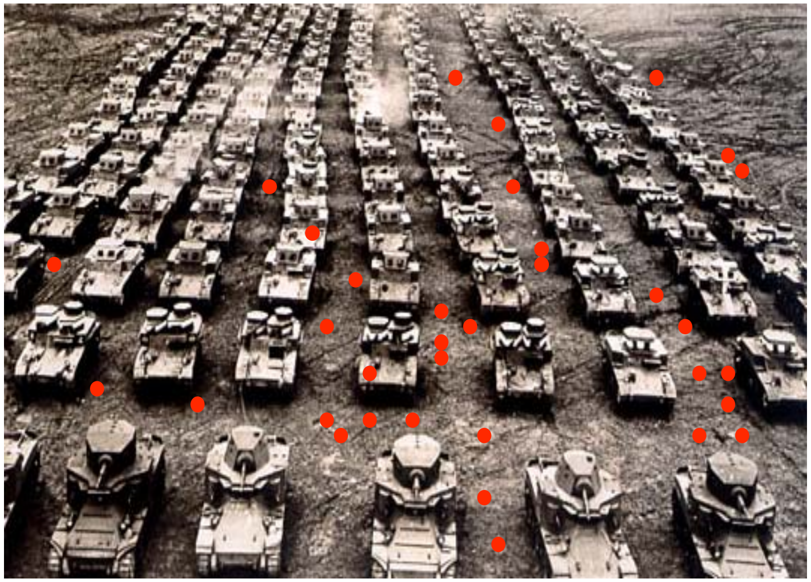
Environmental Surveillance

Use **2D images** captured by the nodes across the field.

Estimate the number of targets

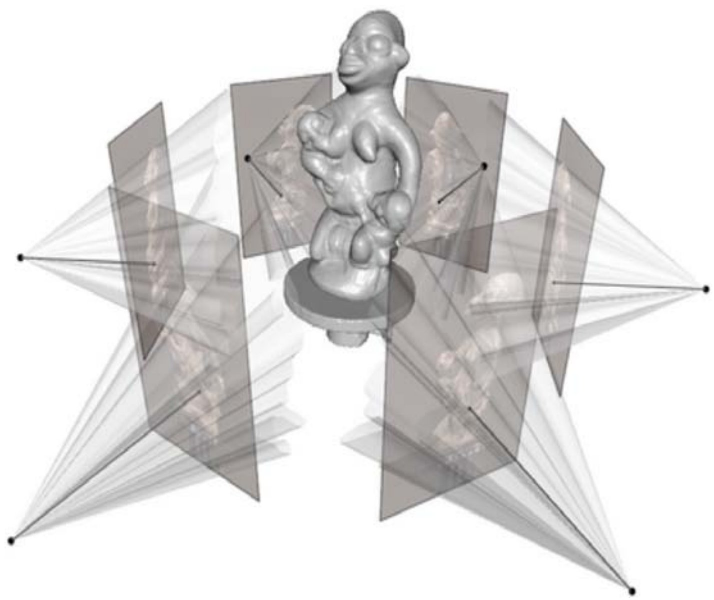
Localize targets

Reconstruct their shape, texture, etc



Visual Coverage

Multi-perspective geometry



www.eng.cam.ac.uk

Each target should be captured (covered by multiple (i.e. at least *k*) nodes

⇩

How many nodes are necessary ?
(Minimum node density)

⇩

Statistics about visual coverage
(parameterized by

node density and target density)

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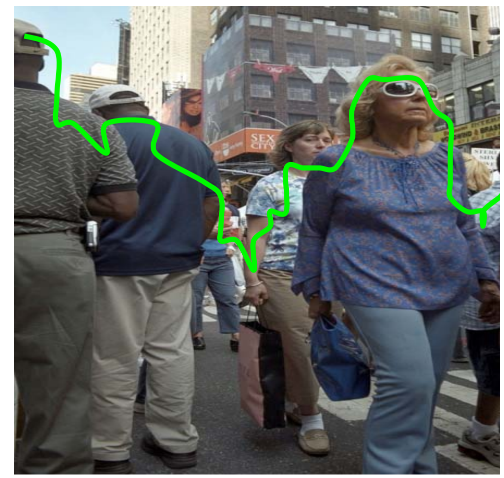
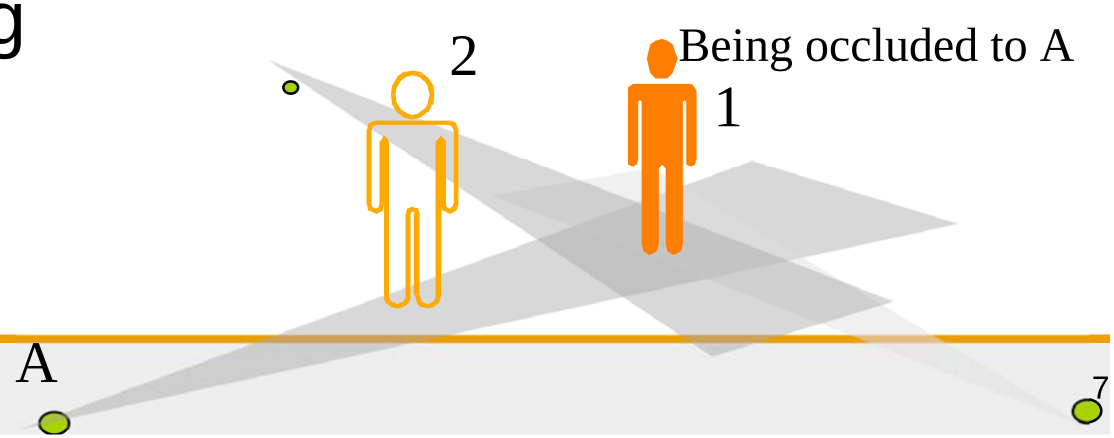
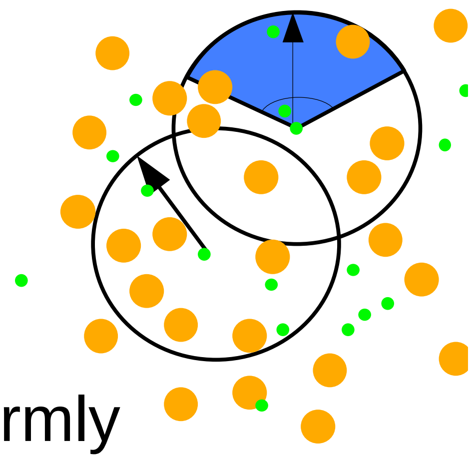
Challenges

- Occlusion
  - A node can visually capture a target only when
    - The target stands in the field of view
    - No other occluding targets
  - Visual coverage is related with
    - Statistical distribution of nodes
    - AND
    - Statistical distribution of targets
- Directional sensing

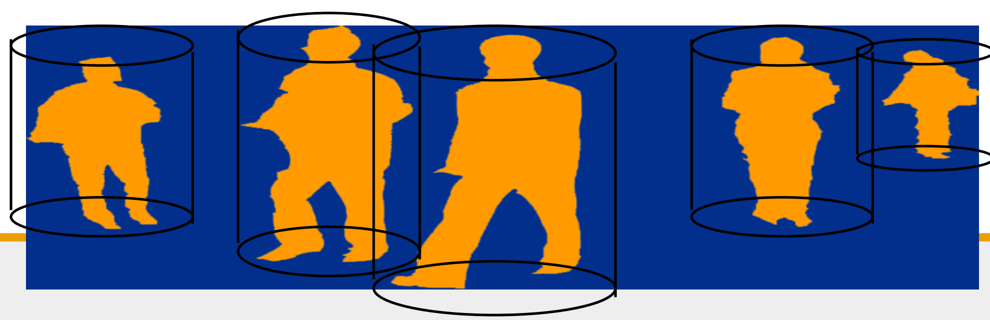




Assumptions



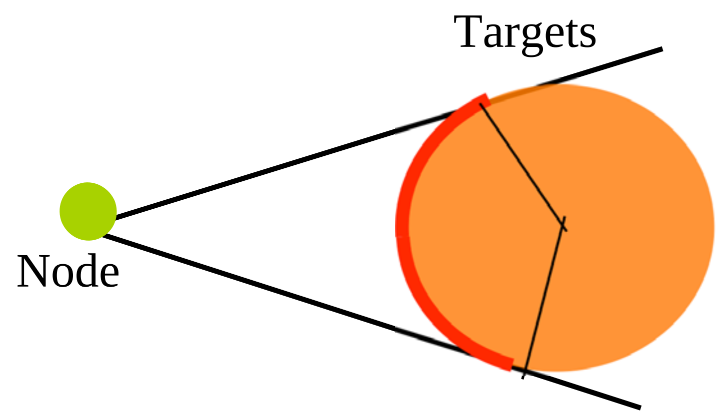
- 2D horizontal sensing field
  - Very large, boundary effect ignored
- Nodes infinitesimal points
  - Poisson point process, orientations uniformly distributed over [0,360), uniform FOV, pointed horizontally
- Target isotropic disc
  - Uniformly located, never overlapping each other, uniform radius

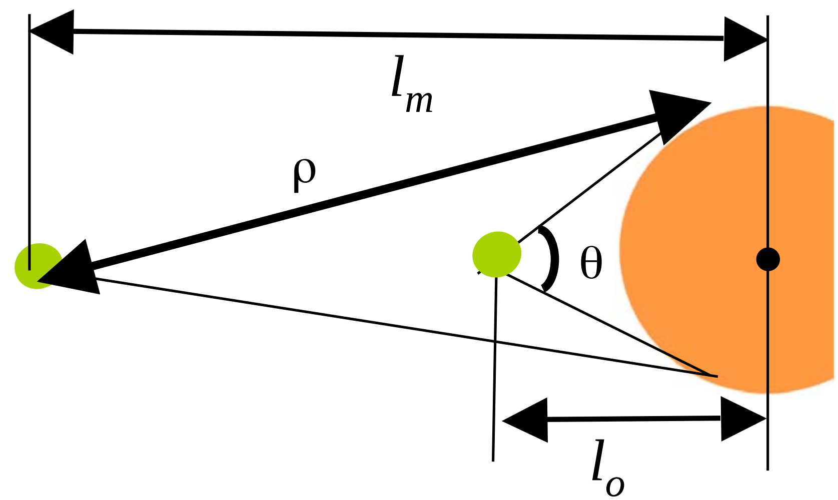


Cylinder target model

Sensing Model

- A node captures a target only when the front arc of the target bounded by tangent viewing rays is completely visible
- Capture range
  - Maximum (l_m): when the target touches the edge of the field of view
  - Minimum (l_o): when the target blocks the entire field of view

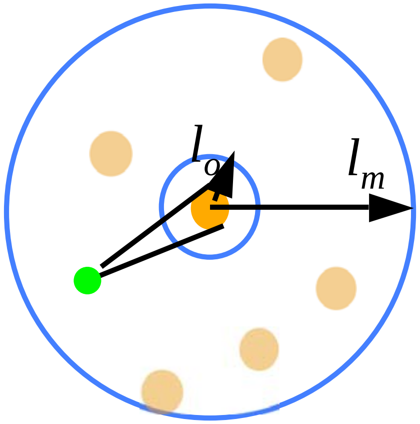


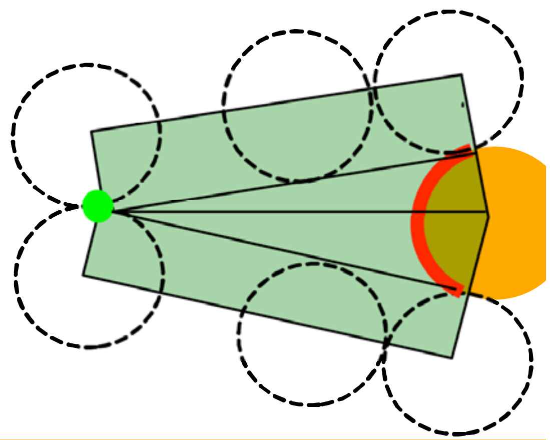


ρ, θ: Range and angle of the uniform field of view of nodes

The Two Conditions

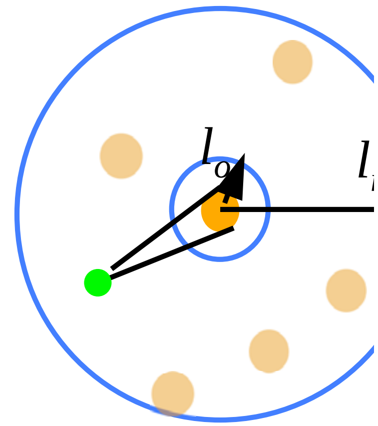
- To capture a target, a node must satisfy two conditions
  - Condition 1: It stands in the ring with outer radius l_m and inner radius l_o centered at the target
  - Condition 2: An in-between occlusion zone is clear of other targets





The Derivation

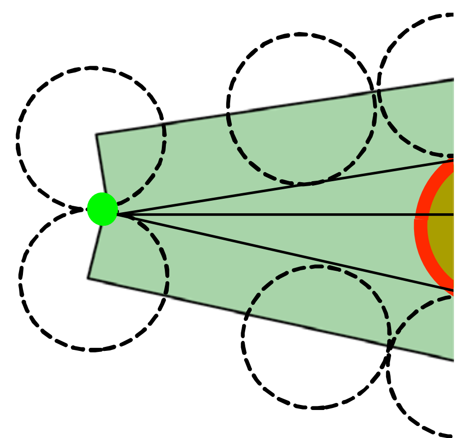
- p(k): The probability that an arbitrary target is captured by exactly *k* nodes
- $\Gamma(k,A,\lambda_s)$: The probability that the ring contains exactly *k* nodes
- q: The probability that an arbitrary node within the ring captures the target
  - A random value with respect to the randomness of the locations of other targets
  - f(q): pdf of q. Very difficult to derive



λ_s: node density
A: area of the ri

$$p(k)=\sum_{i=k}^{\infty}\Gamma(i,A,\lambda_s)C_i^k q^k(1-q)^{i-k}=\Gamma(k,qA,\lambda_s)$$

$$p(k)=\int\Gamma(k,qA,\lambda_s)f(q)dq$$



$$\Gamma(k,A,\lambda_s)=e^{-\lambda_s A}(\lambda_s A)^k/k!$$

How to Find f(q)?

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- The derivation of several significant statistical parameters of q,
  - Minimum value of q
  - Maximum value of q and the corresponding f(q)
  - Expectation of q
- To construct an approximation function ~f(q) based on these parameters

$$p(k) = \int \Gamma(k, qA, \lambda_s)\, \tilde{f}(q)\, dq$$

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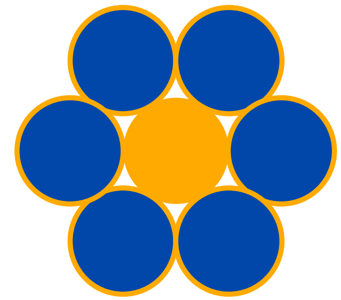
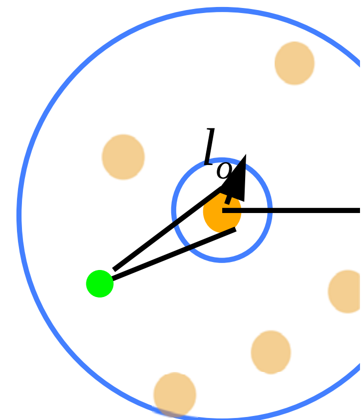
Minimum and Maximum q

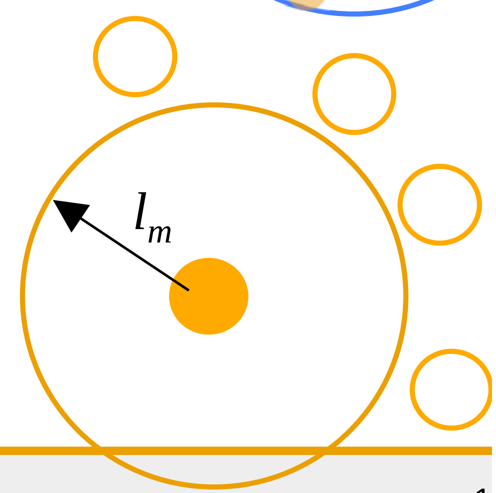


- Minimum q (crowded)
  - When the target is tightly surrounded by six other targets
  - Only nodes falling into the tiny (white) area have the chance to capture the target



$$q_o \approx 0$$

- Maximum q (empty)
  - When the entire ring is empty
  - Nodes are only required to face the target



$$q_m = \frac{1}{A}\int_{l_o}^{l_m} \left[\theta - 2\sin^{-1}(r/l)\right] l dl$$

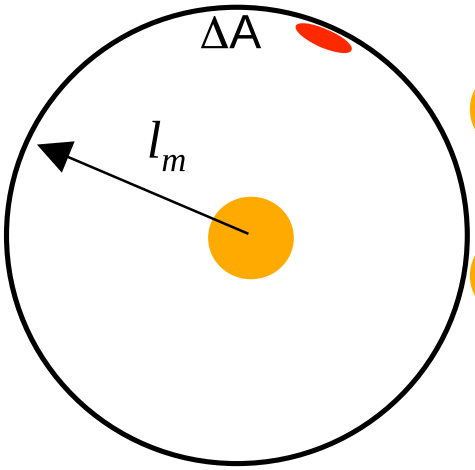
Probability when $q=q_m$

$$F_m = \Gamma(0, \pi(l_m + r)^2, \lambda_t) = \exp(-\pi(l_m + r)^2 \lambda_t) \neq 0$$

- This says that f(q) has an impulse at q_m with amplitude F_m
- What is left-hand limit of f(q) at q_m?

$$\Delta q = \Delta A \sin^{-1}(r / l_m) / \pi$$

Probability that $q \in [q_m - \Delta q, q_m)$

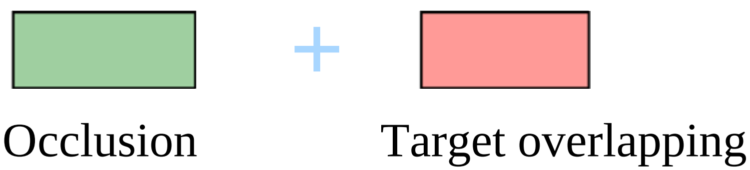


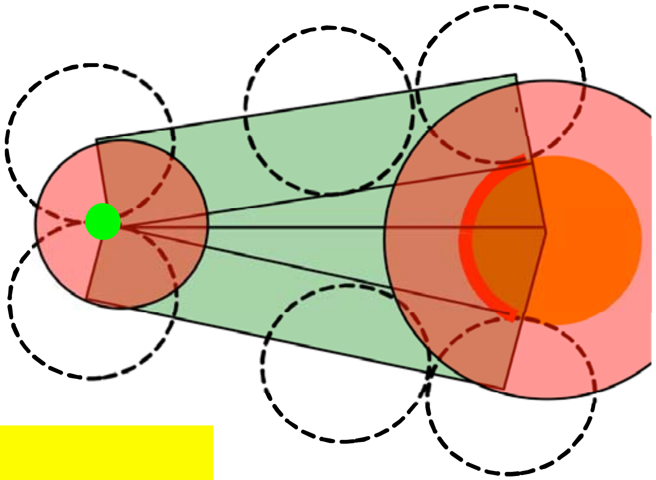
$$\Delta F = \Gamma(0, \pi(l_m + r)^2 - \Delta A, \lambda_t) - \Gamma(0, \pi(l_m + r)^2, \lambda_t)$$

$$f(q_m^-) = \lim_{\Delta A \to 0} \frac{\Delta F}{\Delta q}$$

Expectation of q

- Zone that other targets are forbidden to enter (area A_{FB})





$$E(q) = \frac{1}{A}\int_{l_o}^{l_m}\left[\frac{\theta - 2\sin^{-1}(r/l)}{2\pi}\right]\Gamma(0, A_{FB}, \lambda_t)2\pi l\,dl$$

Average over the entire ring

At a certain point in the ring, the probability that the node is oriented towards the target

Probability of an empty forbidden zone

Approximation of f(q)

- Approximate function
  - A scaled Binominal distribution and an impulse function

$$= \begin{cases} \dfrac{(1-F_m)N}{q_m} C_N^i \gamma^i (1-\gamma)^{N-i}, \; i = int(Nq/q_m) & if \; 0 \le q \le q_m^- \\ F_m & if \; q = q_m \end{cases}$$

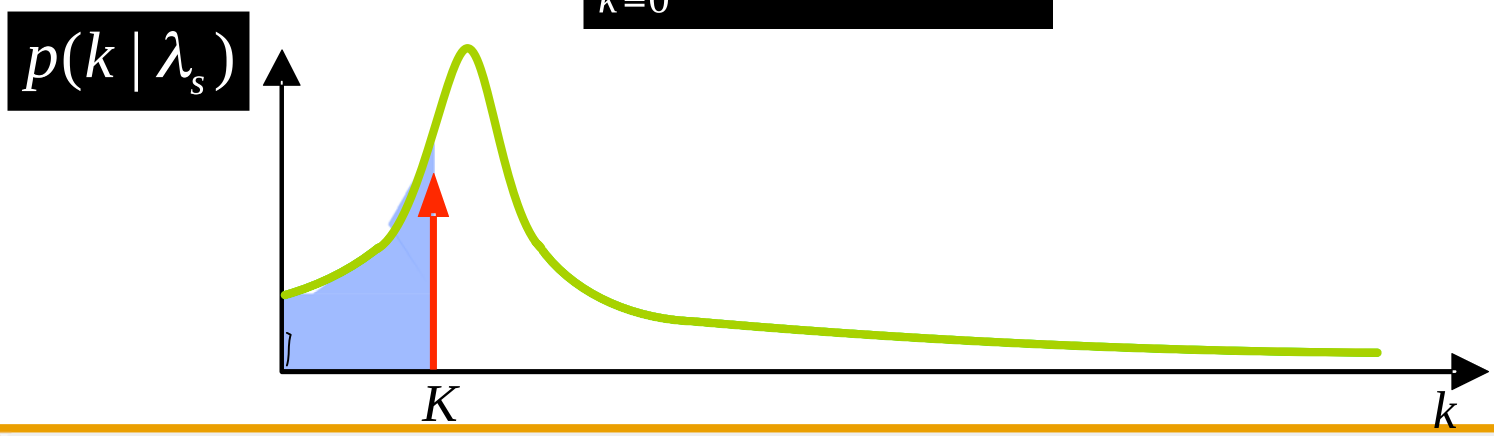
$$(1-F_m)\gamma q_m + F_m q_m = E(q)$$

$$\frac{(1-F_m)N}{q_m}\gamma^N = f(q_m^-)$$

Minimum Node Density

- To ensure the probability that an arbitrary target is captured by less than K nodes is smaller than e, the minimum node density ~λ_s should be the smallest positive root of

$$\sum_{k=0}^{K-1} p(k \mid \lambda_s) = \varepsilon$$



Simulation Results

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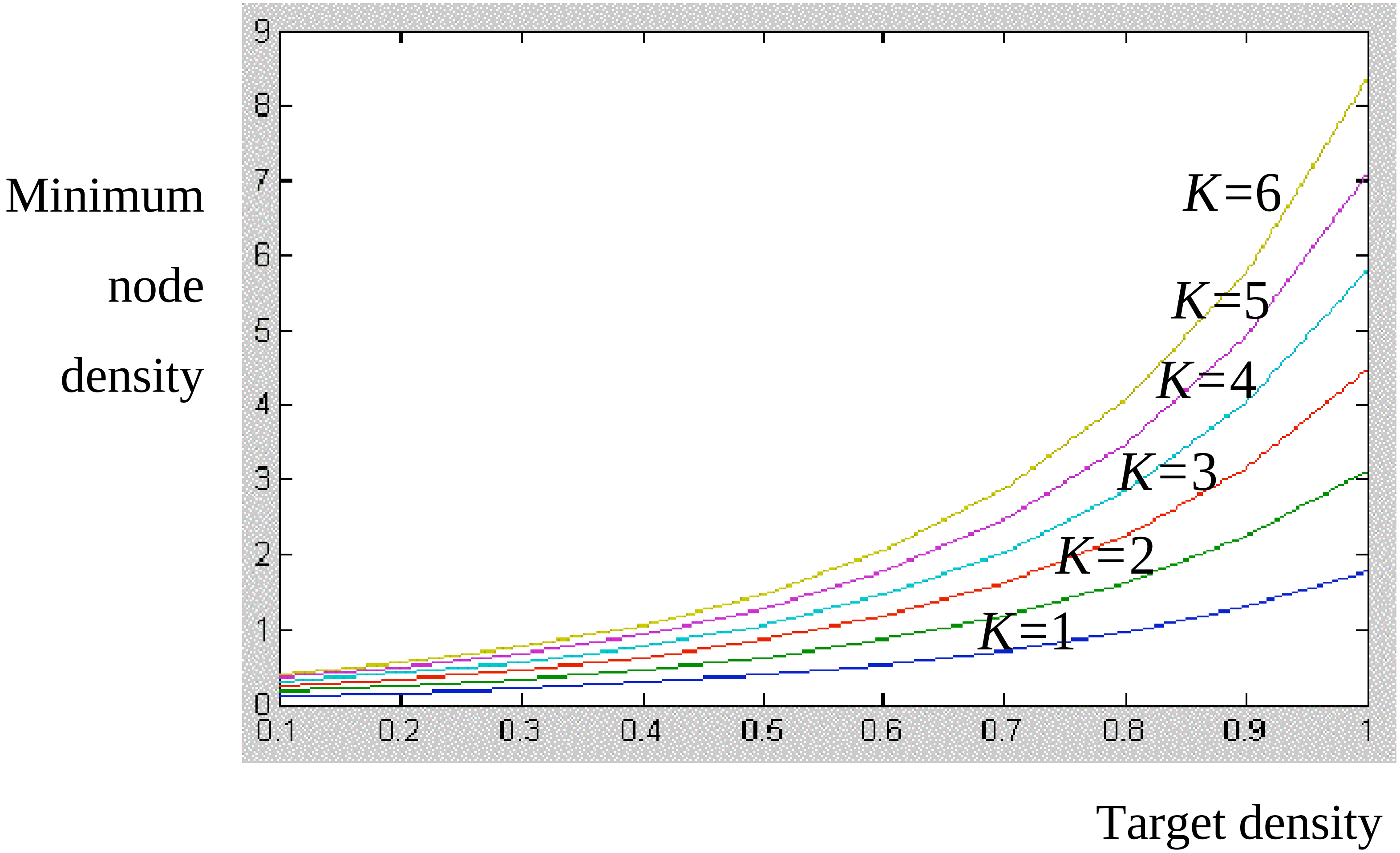

Reference

- C. Qian, H. Qi, "Coverage estimation in the presence of occlusions for visual sensor networks," *International Conference on Distributed Computing in Sensor Systems (DCOSS)*, Santorini Island, Greece, June 11-14, 2008.