Localization using Mobile Wireless Sensor Networks

Course Project - EE 617: Sensors in Instrumentation

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What are WSNs? What are we doing with WSNs?

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- WSNs for localization, and improving conditions of living for animals and humans at IIT Bombay

Improvements in Wireless Sensor Networks

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Optimizations $\rightarrow$widespread applications of WSNs

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  $\rightarrow$Wireless Sensor Network of ZigBees: relative signal strengths for trilateration-based localization.

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- Mobile Target Tracking (MTT) problem: find the moving path of a target in a field based on target locations that are sampled at random intervals

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- Information: processed using leader-based algorithms or distributed algorithms.

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Why a new navigation system?

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Why a new navigation system?

- Unlike open environments, locations with several obstructions or jamming hinder the proper functioning of the Global Position System (GPS).
- In such scenarios, it is necessary to develop a positioning system that can complement GPS.

What is the Pedestrian Navigation System?

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  - The NavMote (sensor on the user) exchanges information with NetMotes (predetermined sensors) when they are in range,
  - otherwise it works on its own.
- Tested in both indoor and outdoor environments: distance accuracy $\pm 1\%$, heading accuracy 1°

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Beacon-based Localization

[5] H-q Cui et al. "Three-Mobile-Beacon Assisted Weighted Centroid Localization Method in Wireless Sensor Networks". In: *Int. Conf. on Software Engineering and Service Science* (2011).

Beacon-based Localization

- Beacon-based localization of mobile targets:
  - some beacons are aware of their positions,
  - they provide geographic information to ordinary sensor nodes to localize,
  - the precision of localization increases with the number of beacons
- Cui et al.[5]: algorithm utilizing mobile beacons that traverse the network deployment area and broadcast beacon packets to generate a number of virtual beacons

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- The distance between the sensor node and the beacon can be calculated using RSSI (Received Signal Strength Indicator).
- Single-mobile-beacon system: co-linearity due to the straight line moving trajectory of the mobile beacon
  $\rightarrow$three-mobile-beacon-assisted mechanism: the sensor node, S_i is localized as the weighted centroid of the three beacon positions:

$$S_i(\hat{x}_{si}, \hat{y}_{si}) = \frac{\sum_{j=1}^{m} w_{ij} V_j(x_{vj}, y_{vj})}{\sum_{j=1}^{m} w_{ij}}, w_{ij} = \frac{1}{(d_{ij})^g},$$

  where V_j is the jth virtual beacon, d_{ij} is the distance between S_i and V_j, and g is an adjustable degree.

Localization Schemes

Localization Schemes

- Anchor node-based schemes:
  - anchors acquire their positions in advance using GPS systems or artificial arrangement to locate unknown nodes
  - better localization accuracy
- Anchor node-free schemes:
  - unknown nodes are located using the connectivity information between unknown nodes and anchor nodes
  - smaller number of anchor nodes $\rightarrow$smaller energy consumption and hardware cost of WSNs

LMAT: An Analysis

[6] J Jiang et al. "LMAT: Localization with a Mobile Anchor Node Based on Trilateration in Wireless Sensor Networks". In: *IEEE Global Telecommunications Conf.* (2011).

LMAT: An Analysis

Jiang et al.[6]:

- mobile anchor nodes - maximize the localization accuracy + decrease the energy consumption of WSNs
- Mechanism:
  - An anchor node moves based on an equilateral triangle trajectory in a WSN area and broadcasts position and time messages periodically
  - On reception, the messages are used via RSSI-based trilateration to determine the position of unknown nodes
- Pros and cons:
  - Reduces the number of beacon positions, trajectory lengths and node density
  - Remains robust at high traveling speeds of the anchor node
  - Sensitive to the standard deviation of noise

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Yu & Ephremides[7]:

- A typical WSN: a number of sensor nodes + control center.

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- Sensor node:
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- Control center: makes a final decision based on all the data it receives from the sensor nodes

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The Simplified Wireless Sensor Network Model

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Operating Options based on Local Processing and Data Transmission

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- Centralized: Transmission of data to the control center without any loss of information [1]
- Distributed: Transmission of local decision by each sensor node as a binary quantity to the control center [2]

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Operating Options based on Local Processing and Data Transmission

Three options for a system of K sensor nodes and a control center:

- Centralized: Transmission of data to the control center without any loss of information [1]
- Distributed: Transmission of local decision by each sensor node as a binary quantity to the control center [2]
- Quantized: Transmission of quantized M-bit quantity after local processing by each sensor node to the control center [3]

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[2] Final decision: based on the K binary quantities

[3] Final decision: based on the K quantized quantities

A Comparison of the Operating Options

The three options are compared based on the probability of error P_e (should be small), the probability of false alert P_f (should be small), and the probability of detection P_d (should be large):

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- The distributed scheme is observed to be superior in energy consumption (especially over large distances) and robustness.
- Although the centralized scheme uses fewer nodes, the distributed option needs fewer than twice that number to achieve the same detection performance.

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- The active and dormant status of sensors can be controlled $\rightarrow$energy consumption is significantly reduced
- This may cause additional discovery latency: discovery is possible only when neighboring nodes have overlapping active slots.

Solving the Neighbor Discovery Problem

[8] Q Niu, W Bao, and S Xia. "An Improved Group-Based Neighbor Discovery Algorithm for Mobile Sensor Networks". In: *Int. Journal of Distributed Sensor Networks* (2014).

Solving the Neighbor Discovery Problem

- Previous research: group-based method - a third state for waking up actively is used to communicate the schedule and verify the neighborhood of nodes

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- Simulations: the discovery time is minimal wrt algorithms in existing literature.

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What is the idea?

- Indian Institute of Technology Bombay - over 500 acres - home not only to humans but also a wide array of plants and animals from leopards and crocodiles to cows, dogs and cats
- Issues for humans from stray dogs + Issues for dogs from human activities
- What can we do? - track and guide dogs without causing harm to both the human and dog populations

Ideas from Mobile Target Tracking

- Based on mobile target tracking[9], a network of distributed sensors may be placed at suitable locations in the institute.

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Ideas from Mobile Target Tracking

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- Large size of the campus $\rightarrow$not a scalable solution (number of sensors and energy consumption will be huge)
- The distribution of dogs across the institute need not be uniform $\rightarrow$Placing sensors at certain locations will not be efficient although there is a possibility for a small number of dogs to visit these areas

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Ideas from LMAT

- The movable sensors on the dogs can behave as anchors[10] using which other movable sensors can localize themselves via trilateration.

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  - three movable sensors are placed such that the size of their point represents the uncertainty of finding their location.

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Into more details

- Neighbors of a sensor - sensors capable of connecting to and providing information about position and time to the sensor for trilateration at that instant

[11] SS Majumder et al. "A dog's day with humans – time activity budget of free-ranging dogs in India". In: *Current Sciences 10(6)* (2014).

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- Geometric uncertainty principle - the uncertainty of the location of the sensor increases given the number of neighbors is less than 4 and decreases otherwise
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  $\rightarrow$Similarly, the three sensors in the simulation are constrained within particular regions

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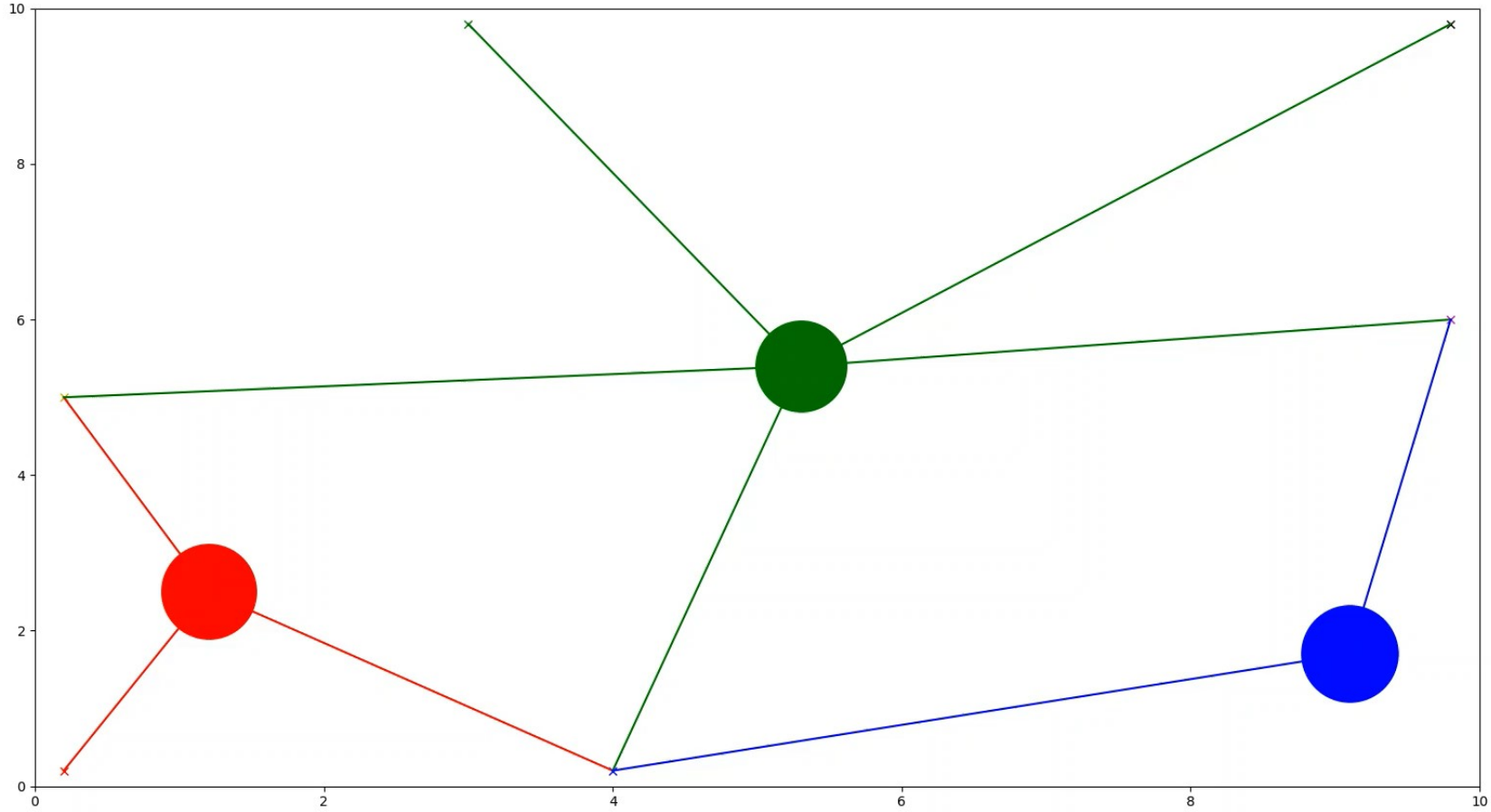

Figure: Initial Configuration - Without Tag Links

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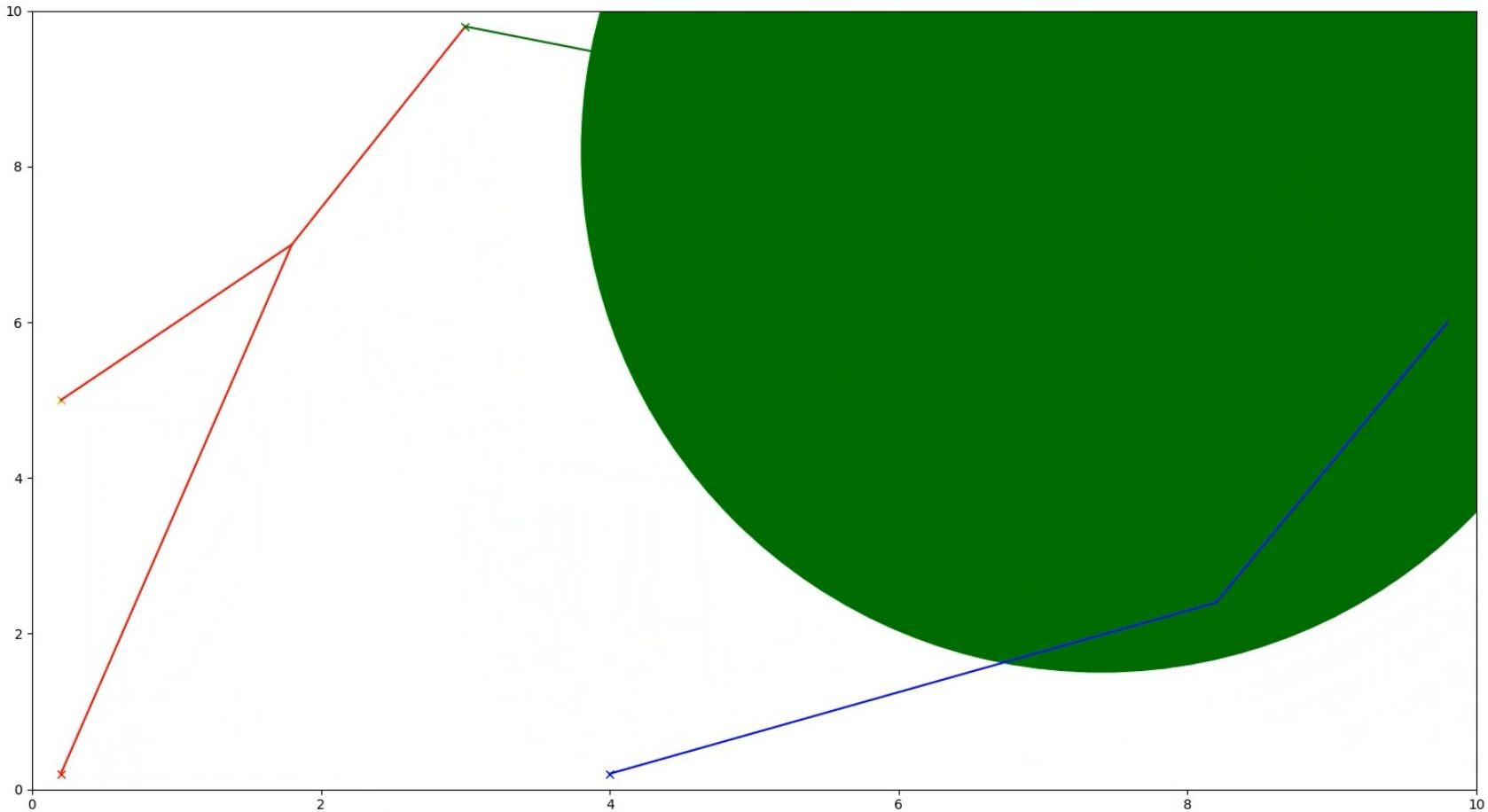

Figure: Final Configuration - Without Tag Links

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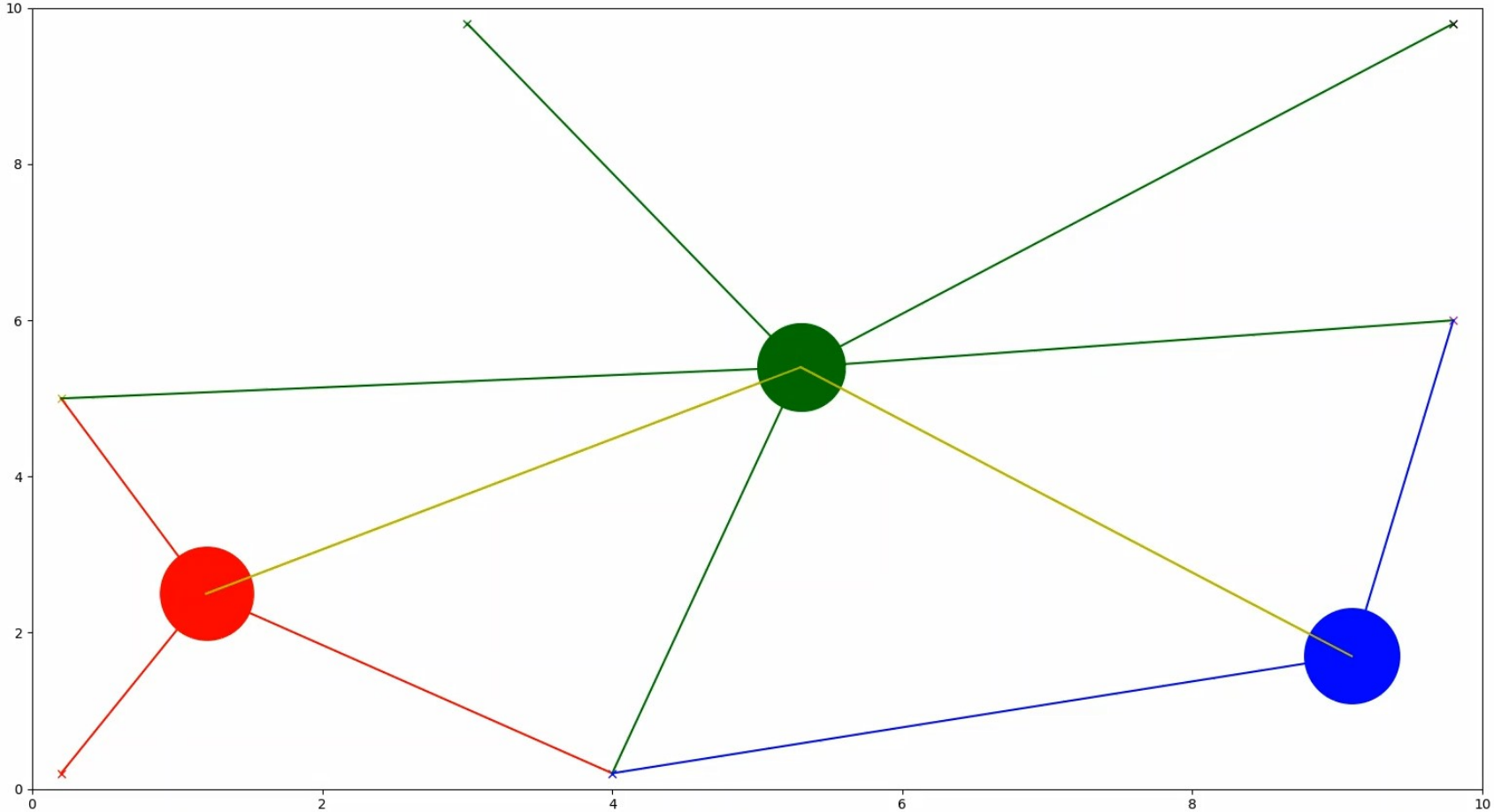

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The uncertainty of the previously mentioned sensors does not diverge since the sensors are in contact with each other for several periods which previously had led to the divergence of uncertainty.

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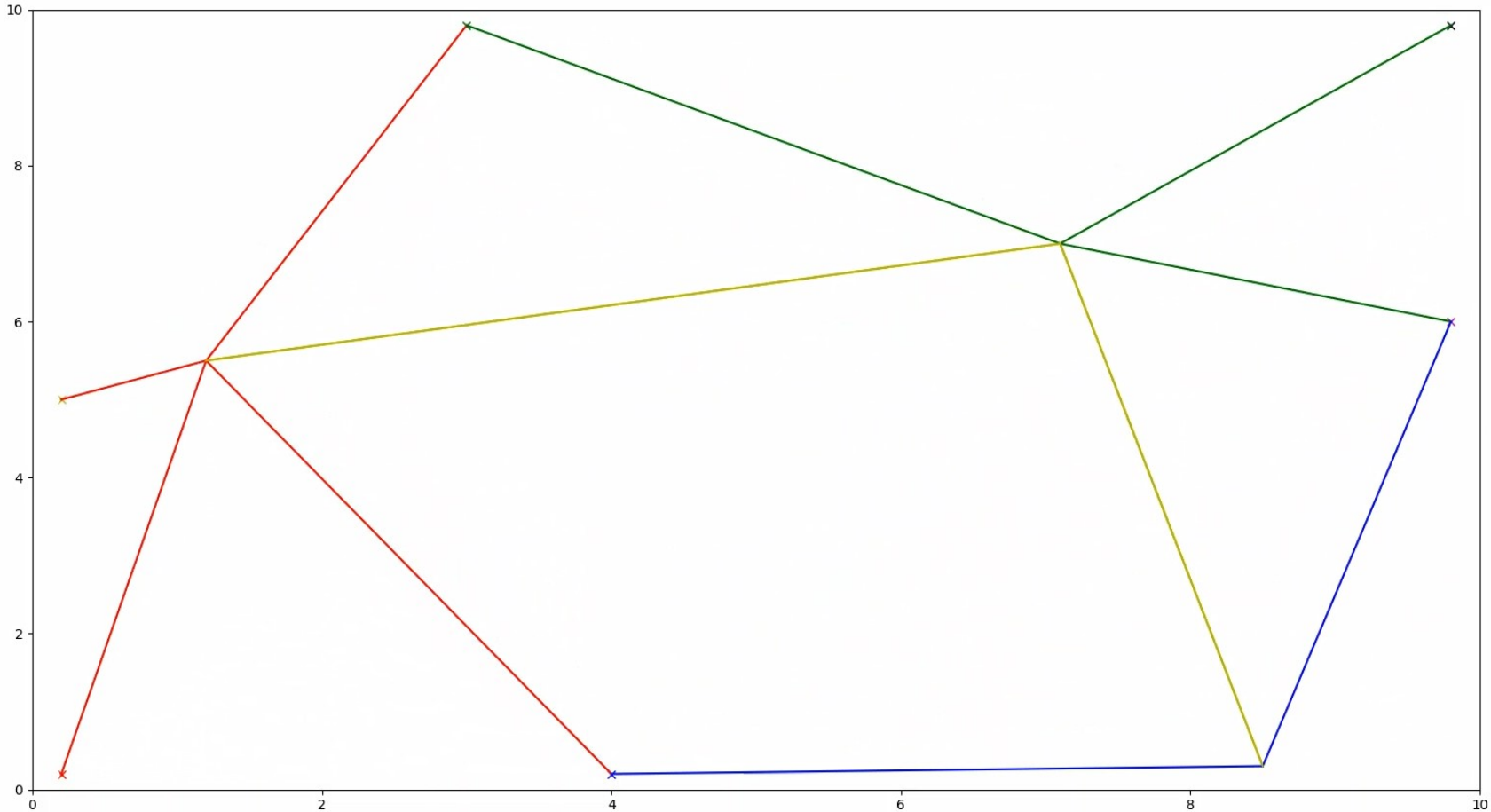

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- Wearing traditional sensors for a long duration may be detrimental to the health of the dog, and the sensing quality may degrade from the environmental and hygienic conditions.
- Biosensors and flexible electronics may be more appropriate long-term options.
- The long-term effects of biologic cybernetics and electronic stimulation on dogs is open to research although there has been progress in short-duration studies on several animals (Johnson and Fuglevan[12], Rezaee and Kobravi[13], Cao and Doan[14]).

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