SMART WIRELESS SENSORS ROUTING PROTOCOL DEVELOPMENT AIMED FOR SMART WIRELESS ROBOT NETWORKS

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We propose a new routing protocol for smart wireless sensors deployed in a wide area for gathering sensitive information. The data is required by data centers or ground control systems, or to be used by drones, rovers and autonomous boats for SLAM and other information needed for mission objectives. The routing protocol will allow creating dynamic networks of drones and wireless sensors, to achieve a grid of data connections.
Keywords: smart sensors, multi-agent system, routing protocol

1. INTRODUCTION

Multi-agent systems composed by drones, rovers and other autonomous or semi-autonomous devices are found in an increasing number of real life applications. The drones are becoming a mobile security camera while rovers provide a reliable mobile control center with a higher autonomy than the flying robots. Among these, there is a special category that has started to become more and more important. This category is formed by smart sensors. These sensors can be mounted on mobile robots (drones, rovers, boats, etc.) or be deployed for short term data acquisition. For all devices, a communication network has to be established that will provide communication links to all agents, even those with no direct communication link to a Ground Control System (GCS) or to a Sensor Data Acquisition (SDA).

The problem we want to solve is the management of the communication network for sensorial data acquisition, to allow hard to access places to be scanned by sensors or to increase the range of the multi-agent system [1] which will allow for the Ground Control System to not be placed in the vicinity of the mission area, protecting the human operators from the mission's contaminated or hazardous environment.

To solve the network problem, the scientific community has different approaches that depend also on the use case. To lower power consumption that powerful antennas to, Kim and Matson [2] proposed a network that uses the city's buses as routing agents, thus increasing the communication range of the drones. For a multi-UAV cooperative control missions, Karaman and Frazzoli [3] proposed a high combinatorial complexity with temporal constraints algorithm using a mixed-integer linear formulation to get the optimal routing decision. The algorithm's decision is based on an already known graph made of the network agents.

Other multi UAV networks have single or multiple clusters [4-5] which offer a good technique for data communication between drones while offering mobility and low latency but depend on the network density to maintain a communication link. The information being sent between drones are required for collision avoidance and flight formation [4]. In this type of networks we can have different data packets delivery systems: unicast, broadcast, multicast and geo-cast. What is important for us is the cooperative routing process which allows communication between two drones that are too far apart. The idea of using other UAVs as relays to provide wireless connectivity [6] is not new and has been used for drone deployment to achieve communication with other network agents which are without any direct line-of-sight transmission link due to obstacles that prevent communication [7-9].

In this paper we are proposing a new routing protocol that will allow a multi-agent system to become more independent of the Ground Control System's position by creating an ad-hoc communication network. The routing protocol is oblivions of the agent's missions and the agent's position inside the grid. The only issue that the operator has to handle is to designate specific missions in order to place agents that will become routing points for the sensorial data sent to GCS/SDA which means that not all drones have to leave the vicinity of the communication system.

2. ROUTING PROTOCOL ALGORITHM

To communicate between autonomous agents inside a network or for the agents to send their data to a data acquisition system or a ground control system, we require a way for the agents to decide how to send their data in a safe manner, preventing data loss. For this we have used a classic routing protocol [10] and applied it to a network of robotic agents.

Routing Protocols Main Steps:

- Step 1: Discovery
  - The agent will identify all other agents around itself
  - The agent will acquire the surrounding agents parameters
- Step 2: Route management
  - The agent will keep track of the discovered surrounding parameters by refreshing its list (through Discovery – Step 1) at fixed intervals.
- Step 3: Path determination
  - The agent will choose the shortest and safest path to transmit its data to the Control System. For robotic agents, the control system will be a Ground Control System (GCS) and for sensors the control system can be a GCS or a data acquisition system (DAS)
- Step 4: Sending the data packets
  - The agent will send its data without broadcasting by targeting the selected best node/agent and specifying the end node (GCS/DAS)

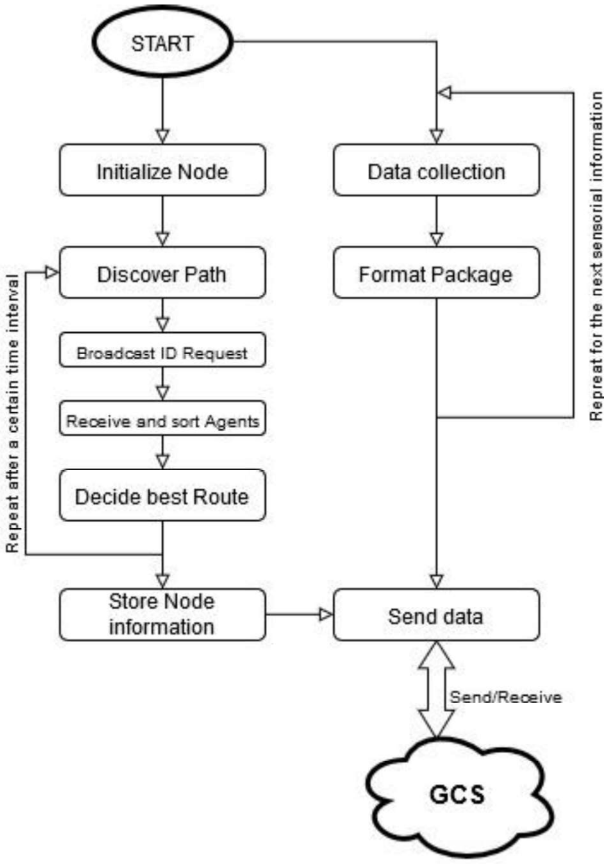

Figure 1 – Summary diagram of the routing path algorithm

The routing protocol algorithm (figure 1) is used to compute the path a data packet will take. What the algorithm does is to search for the best agent that has already a link to a GCS or DAS, otherwise it can risk to send data to agents that have no path to send the received data.

The algorithm to discover the safest path to send the agent data requires storing agent's parameters. The agent's parameters are divided into 3 main sections:

- Agent path to source/control system
  - This is the number of nodes to reach the control system.
  - This value can be 0 when the network in initializing or when the agent has no other path to a GCS or DAS.
- Signal strength divided into three categories
  - Low signal. This can lead to packet loss.
  - Medium signal. Provides average speed to transmit data.
  - High signal. The agent is very close and can be a favorite node to reach the Control System.
- Number of other agents that currently use the node/agent to send data to Control System.

The parameters of each surrounding agent will be taken into account when deciding the best path/route to the destination system (GCS/DAS). Thus the decision is based on the nodes with the best signal strength and a path to the control system. Another important parameter is the number of other agents that currently use the same node for sending their data. If the agent is battery powered, then a high number of agents that will use it as a routing node will result in a short life of that particular agent which is to be avoided if that particular agent or smart sensor is of high importance for the mission.

$$TargetNode = \begin{cases} \boldsymbol{Node}\ where: Node\ has\ connection\ with\ GCS\ AND \\ Node\ Signal\ Strength \geq Medium\ AND \\ \dfrac{NumberOfNodesToGCS * 3 + NodeCongestionLevel * 2}{5} = MIN \\ \boldsymbol{OR} \\ \boldsymbol{Node}\ where: Node\ has\ connection\ with\ GCS\ AND \\ Node\ Signal\ Strength \geq Low\ AND \\ \dfrac{NumberOfNodesToGCS * 3 + NodeCongestionLevel * 2}{5} = MIN \end{cases} \quad (1)$$

The decision can be expressed as formula 1, where the node is the agent through which another one tries to send its data to a GCS or SDA; NumberOfNodesToGCS is the path required for the data to travel between the Node and the receiver GCS/SDA; NodeCongestionLevel is the level of usage of the Node by other nodes in order for them to communicate their data.

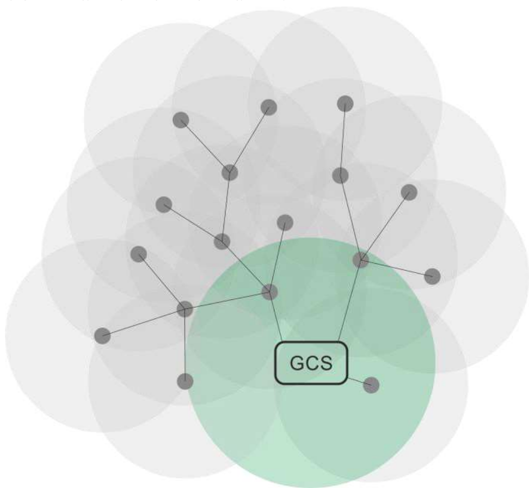

Figure 2 – Routing protocol communication data graph example

For every message sent, the agent requires a confirmation. If the confirmation is not received in a reasonable time, it can assume the path was compromised and can start to find a new route.

This system works for fixed/mobile wireless sensors and for mobile agents who are not in range of the Control System. One example is in figure 2.

3. APPLICATION TO DEMONSTRATE THE USEFULNESS OF THE ROUTING PROTOCOL

To demonstrate in an easy and simple way how the routing protocol will behave in a real scenario with different node conditions (available, defective or detect bottleneck), we have created a simulation software. This application generates randomly in a certain limited area a number of nodes/agents of different types (drones, rovers, smart sensors, etc.) and then lets each node to find its shortest and safest path to the nearest node that can store the agent information (GCS, DAS, etc.).

Figure 3 presents the interface of the simulation application where the interface was populated with multiple agents. After all the nodes have been randomly placed on the working space, the algorithm starts to find the best path for each node. This means that each node will search for its neighboring agents and try to find a path to the GCS and SDA1 (sensor data acquisition), as seen in figure 3.

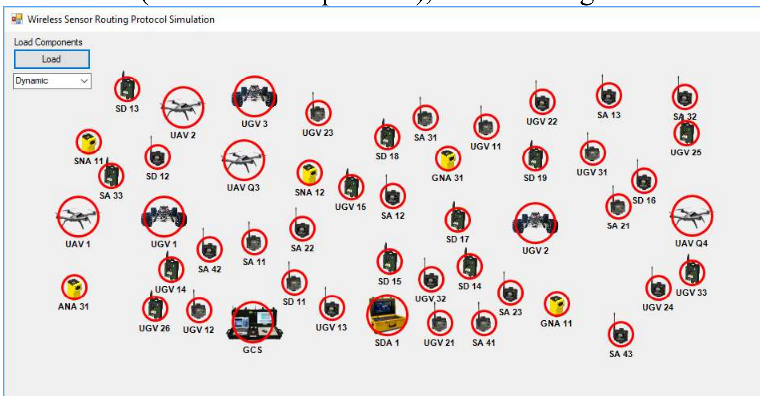

Figure 3 – Routing protocol simulation software with generated agents

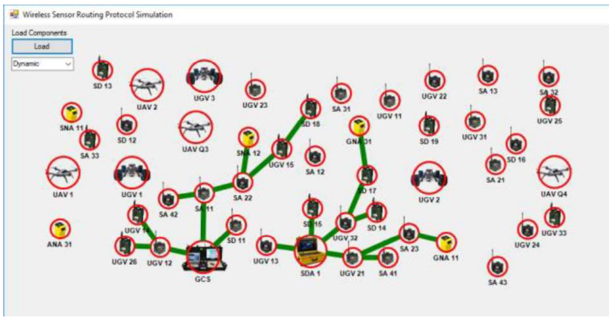

Figure 4.a – First stage of data path generation

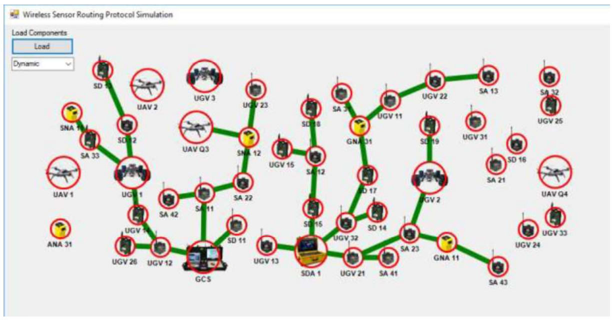

Figure 4.b – Intermediary stage of data path generation

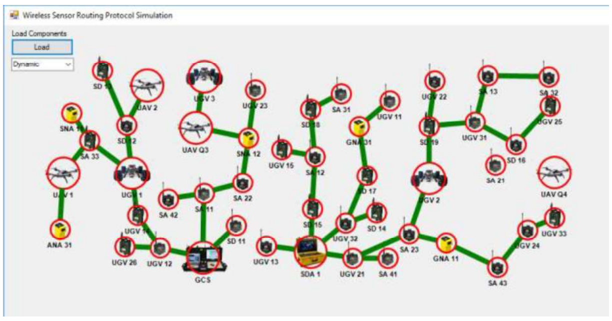

Figure 4.c – Intermediary stage of data path generation

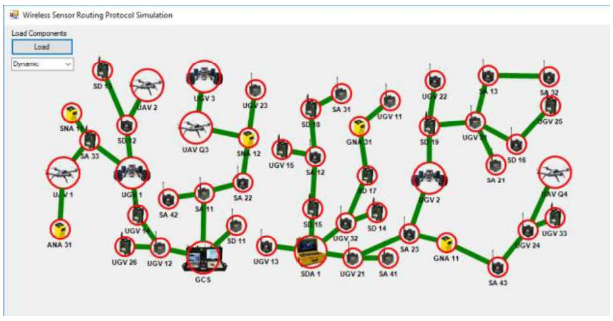

Figure 4.d – Final stage of data path generation

The list of figures 4, presents the path generation of a network of agents and nodes. One can see at each stage how the routing algorithm searches for each node the best neighbor to use as a routing agent. Each node will search for its neighbor nodes and decides which node can and should be used as an intermediary agent in sending its own data to a central system (GCS or SDA).

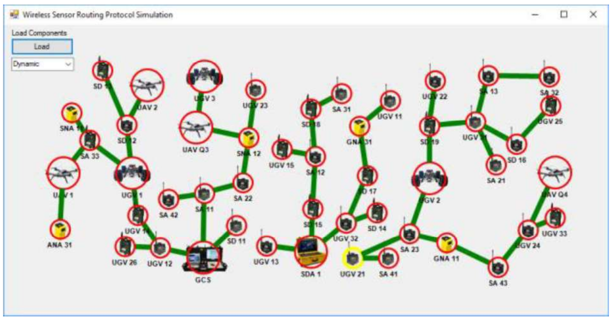

Figure 5.a – Simulation of defective node

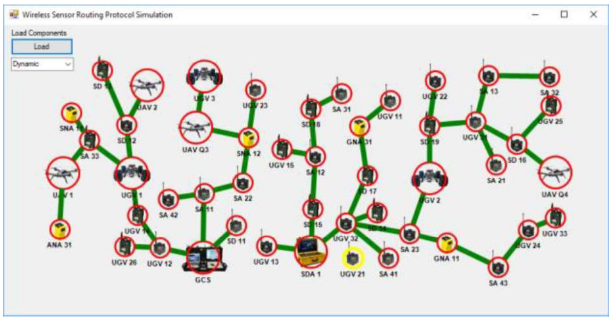

Figure 5.b – Simulation of defective node, routing path regeneration

Figure 5.a and 5.b presents the case when a node/agent stops communicating. In this case the routing algorithm will regenerate the communication path for all required nodes to find a new path to the acquisition system.

The case when multiple nodes stop communicating is presented in figures 6.a – 6.f. In this case, at first only two nodes go offline and the path is being regenerated, and then 7 nodes in total are offline. In this case, we can even see that several nodes which previously had their data communicated to the GCS now send it to SDA1 because the routing algorithm found a better path to send the information. In the end we restore all nodes and see that the regenerated routing paths recover to the initial state (figure 4.d).

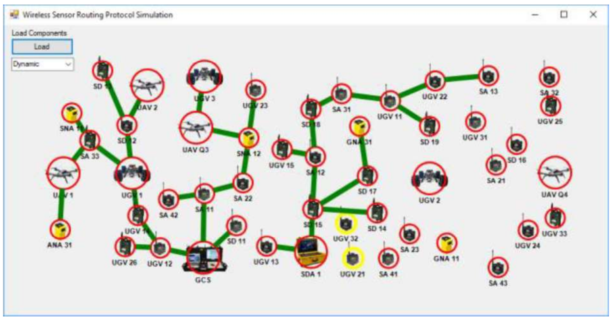

Figure 6.a – Simulation of two defective nodes

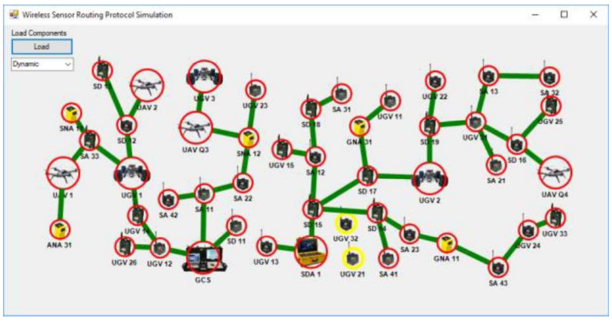

Figure 6.b - Simulation of two defective nodes, routing path regeneration

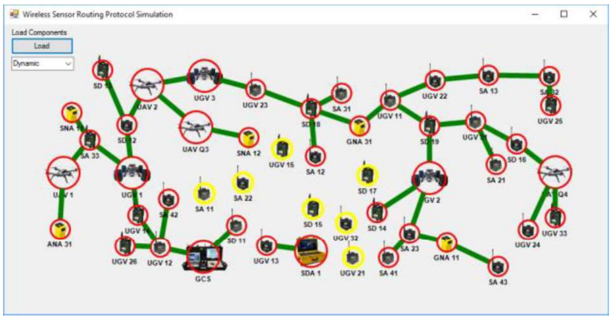

Figure 6.c – Simulation of multiple defective nodes

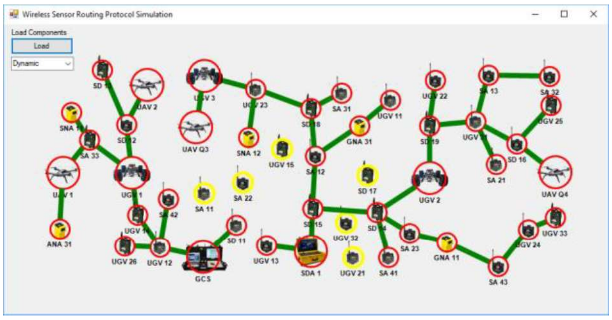

Figure 6.d - Simulation of multiple defective nodes, routing path regeneration

Figure 6.e – Simulation of multiple defective nodes that are again available to send information

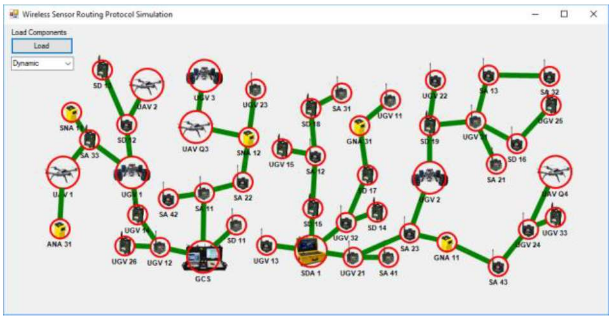

Figure 6.f – Simulation of multiple defective nodes that are again available to send information, routing path regeneration

After simulating the routing path algorithm, we have created a simulation case (figure 7) where we can see the data packets being sent from a source node to its destination. Using this, one can see each data link and how data packets can congestion a nodes bandwidth, creating bottlenecks.

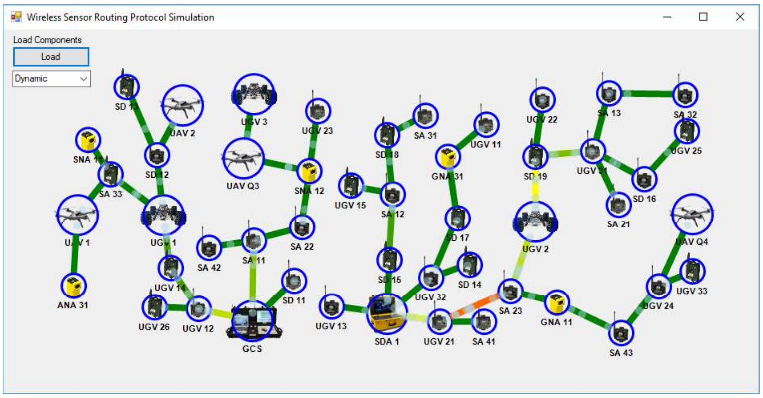

Figure 7 – Color coded data packets communication and bandwidth usage

4. CONCLUSIONS

The applications in which drones and other autonomous or semi-autonomous agents are being used have become more and more complex, where multiple agents are being sent to gather information or to solve a single mission. For this, the human operated control center (ground control center – GCS) has to receive sensor information from the deployed drones or even from the smart sensors placed by human participants or by other robotic agents. This information is critical in missions that try to save or prevent the loss of human lives.

To prevent data loss due to the distance from a mobile robot or smart sensor to the GCS, an ad-hoc network is formed to allow other agents to pass the information, making them a communication routing node. To allow this, the routing protocol was created so that any agent can become a routing node and the sensorial information required by the mission control will actually reach it.

The current routing protocol has a few issues to be solved by later versions. One of these is that a node can become heavily used for data communication. The first result is that the agent will be delayed in sending its own information. The other, which can be more severe, is the battery consumption. Since most of the deployed drones and smart sensors relay on their battery for data acquisition, mobility and communicating with the control center, a heavy use of the communication devices can put a heavy stress on the battery which will drastically reduce the agent's mission time.

Further improvements of the routing protocol will take into consideration the battery life of the node, to prevent draining the power of important agents while others can be deployed by the operator can have a single mission, allow communication over long distances with GCS or SDA.

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