# ADVANCED COMMUNICATION PROTOCOLS FOR SWARM ROBOTICS: A SURVEY

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## ABSTRACT

Swarm robotics is the application of swarm intelligence that is inspired from natural swarms such as ant colony, bee hives, flock of birds etc. Ants communicate by laying down a pheromone trail to help other ants trace the shortest path from nest to the food source. This indirect communication is called "Stigmergy". Bees communicate by making a waggle dance that indicates the distance to food source and how much rich the food source is. In artificial swarm the behavior is implemented with wireless communication using autonomous mobile robots or unmanned air vehicles. The communication strategy is a key parameter that needs to be studied and analyzed in detail. This paper presents the recent wireless communication protocols and their advantages and disadvantages for each. This survey gives a summarization of most communication methods used for swarm robotics.

**KEYWORDS:-**Wireless communication, swarm robotics, Ad-hoc networks, sensor networks.

## I. INTRODUCTION

In natural swarming, individuals communicate between each other and their environment in order to perform a collective task, communication between individuals happen by affecting the environment like individuals in ant colony where ants exchange information by laying down a chemical substance trial called pheromone to stimulate other ants in the colony, and help them find the shortest path between their nest and the food source, this mechanism called Stigmergy.

Bees communicate by making a dance called waggle dance. This dance gives two indications, the direction of the food source and the distance to the food source. Individuals in bee hives determine the direction by knowing how the intended bee shake her body left or right, and they can determine the distance by the duration of the waggle dance [1].
Swarm of robots can be used in different applications such as exploring, search and rescue, military, etc. There are various wireless communication protocols used in swarm robotics, based on the application and environment the robots work with, the communication protocol can be chosen either indoor or outdoor, short range or long range, high data rate or low data rate. Wireless communication frees the

robots from cables, but it suffers from several significant drawbacks, such as limited bandwidth, high power consumption and the lower communication range. Widely used communication methods for making robots interact are infrared, Bluetooth, Wi-Fi, ZigBee, etc. Wireless sensor networks used for both indoor and outdoor robot applications. In swarm robotics the communication method represent a major issue, however all other robot parameters in control, coordination, localization and navigation based on the communication methods.

- **Indoor communication** is used when robots move inside a building and need to be traced, such as in factories, industrial warehouses, hospitals, libraries etc. this type of communication requires more power to go through walls of building, usually high data rate and not necessary long range. Examples are Wi-Fi and Bluetooth.

- **Outdoor communication** used when robots move outside the buildings and need to be accessed and control in a distributed environment such as in exploring an open area, agriculture, military actions, tracing, etc. This requires the communication standard to be of longer range with low data rate such as ZigBee.

Fiberglass cables was used in [2], the authors assume a disaster scenario (like earth quake) where many rescue teams of different countries may exist at the same place, and each team has its own robots and wireless network which may lead to block parts of the scarce resources with the wireless networks, but using cables with mobile robots is not practical since they reduce mobility and may be broken or cut at any time.

Infrared used as short range to send control signal used by individual to recognize each other, Bluetooth is used for about 100 meter range with high data rate, RF used as point to point communication with low data rate, Wi-Fi also used for hundreds of meters range in the presence of many access points with high data rate, and ZigBee protocol was developed for longer range, low data rate, with primary advantage of the this protocol lies in its ability to offer low power and long battery life.

## II. COMMUNICATION PROTOCOLS USED WITH ROBOTS:

### 3.1 Infrared communication

Infrared communication goes very small distances, and its signals cannot penetrate walls or other obstructions and work only in the direct line of sight. Infrared is used for short distance communication to transmit and receive data among robots to recognize each other and also used as sensors to detect obstacles in the working environment.

In [3] a short range communication based on Pulse Width Modulation (PCM) used for autonomous mobile robot. IR devices were used to send and receive data packets, the reflected infrared signal is also used for distance estimation [4] for obstacle avoidance. Infrared devices also used in remote control for a personal robot called "Maggie"[5], it works by natural commands in human terms to communicate with the robot, a user speak to the robot, and the robot can understand the speaking by a speech recognition software.

### 3.2 Bluetooth Communication

Bluetooth communication or (802.14.1) standard originally developed for peripheral communication, between computer and printer, cell phones, cameras, GPS modules and headset, etc, its range starts from 10 meter and goes up to 100 meter in ideal case as shown in table 1, the data rate is up to 24Mbps, it can be used in both indoor and outdoor robot applications.

Bluetooth transceivers can be integrated to a mobile robot to establish a connection between a robot and a server as in reference [6] where a robot platform called "Aibot" was used and controlled in centralized mode from a computer using Java program. Another work used Bluetooth found in [7], a new cheap developed robot platform used in distributed swarm robotics.

Table 1 Bluetooth Power Classes

| Class | Maximum Power | Minimum Power |
|-------|---------------|---------------|
| 1 | 100 mW | 1 mW |
| 2 | 2.5 mW | 0.25 mW |
| 3 | 1 mW | - |

### 3.3 Wi-Fi Communication

Wi-Fi is also known as (802.11) standard and wireless LAN (WLAN) is used for indoor communication, its range up to 100 meters and more than that in case using many access points, its high data rate goes till 54Mbps, this standard if used as transceivers onboard with a robot, it consumes a lot of power, and microcontrollers that represent the brain of robots will not be able to process such high data rate, so it is not practical to use Wi-Fi with swarm robotics because it will make the battery discharge quickly as per current technology of writing this paper. A simulation program was used in [8] to build network architecture of mobile robot over an existing network infrastructure; the robot platform used is Pioneer P3-DX.

The robot Pioneer 2-DX was used in a centralized swarm robotics, a RobART III robot was acting as a lead robots and four Pioneer 2-DX robots as autonomous mobile relays to extend the effective range of the robots exploring a complex interior environment. To extend the range of digital radios and provide non-line-of-sight service, the use of dropped static relays or autonomous robots as relays have been discussed in [9].

### 3.4 ZigBee Communication

ZigBee protocol uses 802.15.4 standard as baseline, it is designed to build wireless mesh networks that are used when the distance of two nodes is more than the communication range of the two nodes, other nodes in between can work as router to retransmit the message to the last destination. ZigBee protocol added following three things to the 802.15.4 standard [10]:
- Routing: routing tables enable nodes to pass messages to neighbor nodes (multi-hop) to destination.
- Ad hoc networks: building a network without human intervention.
- Self-healing mesh networks: automatically discover the failure and reconfigure the network with new route.

Devices from different vendors can communicate with each other if designed to support ZigBee protocol. These devices recently commonly used because of the following features: low power consumption, low data rate, low cost, large number of nodes, longer range (more 1 Km with XBee Pro), short time delay and high reliability.

Table 1. Main features for wireless communication protocols

| S.N | Property | IrDA | Bluetooth | Wi-Fi | ZigBee |
|-----|----------|------|-----------|-------|--------|
| 1 | Standard | - | 802.15.1 | 802.11 | 802.15.4 |
| 2 | Physical media | Infrared | RF | RF | RF |
| 3 | Communication Range | Few meters | 100 meter | 100 meter | >100meter |
| 4 | Maximum Data Rate | 4-16 Mbps | 2-24 Mbps | 54 Mbps | 250 Kbps |
| 5 | Frequency Band | 405THz - 300 | 2.4 GHz | 2.4 GHz | 2.4 GHz |

| | | GHz | | | |
|---|---|---|---|---|---|
| 6 | Max. Number of Nodes in Network | - | 8 | 2048 | 65000 |
| 7 | Security (Encryption) | - | authentication and optional encryption | WEP, WPA, RC4 | AES |
| 8 | Power consumption | low | Medium | High | Low |
| 9 | Network Topology | Point to multi-point | Ad hoc | Star | Ad hoc, Mesh |
| 10 | Traffic controller unit | - | Master | Access Point | Coordinator |

## III. WIRELESS NETWORKS IN SWARM ROBOTICS

### 3.1 Mobile Ad-hoc Networks (MANET)

Mobile Ad-hoc Networks (MANET) are wireless communication networks that do not need infrastructure network devices such as routers or switches in the work place; which means there is no central control on the nodes (self-organized), the protocol handles dynamic topology which make it suitable with a swarm of robots.

MANETs are fast deployment and used to avoid problems could happen after a disaster that lead to discontinue of the various networks such as internet connection and electricity. It consists of mobile nodes in a distributed structure. Therefore this type of networks can be used in swarm robotics applications like exploring unknown environment and search and rescue tasks as in [11] where a disaster scenario covered is a large industrial warehouse in a fire, the ad hoc networks increase the coverage area of the fire fighters and can provide position data to support localization of the mobile robots. authors of [12] present the background of ad-hoc robot wireless communications, and their applications.

### 3.2 Wireless Sensor Networks (WSN)

Wireless sensor networks are networks that are based on distributed nodes in predefined space or any environment, and usually used to monitor the environment conditions in real time using sensors with limited processing power, memory and power supply. Applications of WSN such as monitoring temperature, pressure, humidity, light intensity, sound and vibration, etc. mobile wireless sensor networks are used in swarm robotics application due to its characteristics in sensory and mobility.

There are many research work combining WSN and mobile robots however wireless sensor networks have sensors to collect information from the environment, but lack the mobility, Mobile robots have the mobility feature with limited sensory, combining the two will produce a solution for various problems related to mobile robots as well as wireless sensor networks. The researchers of [13] used WSN to access and control mobile robot in unstructured environment as the robots are equipped with a sensor node and deployed on environment already monitored by unstructured WSN, also applied to solve the problem of tracking in mobile robots [14] the authors propose a intrusion detection algorithm based on collecting light signal and routing protocol, the intrusion detection algorithm with the routing algorithm are implemented in WSN consists of MICS2 sensor motes. The sensors are programmed to perform tracking based on detection of light signals. Another work for tracking with WSN found in [15] propose a design architecture for tracking algorithm to trace a mobile target while ignoring others. An indoor navigation system for autonomous mobile robots using WSN is presented in [16].

Combine with ZigBee protocol WSN applied for positioning and navigation for robot [17]. based on the Received Signal Strength Indicator (RSSI) and coordinates of the reference nodes, the blind node (mobile robot) computes the distances from reference nodes. RSSI is a function of power transmitted and the distance between transmitter and receiver, it defined in this formula:

$$RSSI = - (10\, n \log_{10} d + A) \qquad (1)$$

Where: n is constant related to the signal transmission power with the increasing distance, d is distance between transmitter and receiver, A is the value of the average power at reference distance of one meter. In [18] an algorithm used the same concept of RSSI to estimate distance between the nodes in WSN and reference nodes based on Zigbee protocol. The positioning problem of mobile robot also solved using WSN with ZigBee [19].

This paper presents a method for positioning mobile robot based on ZigBee WSN and a vision system where a ceiling light used as a land marks. WSNs are also applied to solve localization problems and different solution for the navigation problem is presented [20-21]. The requirements for a sensor network communication infrastructure are therefore similar to robotic swarms, but differ in the mobility of nodes, Another difference which is being caused by node mobility is optimization of energy consumption. An algorithm based on processing of radio signal strength data was developed so the robot could successfully decide which node neighborhood it belonged to however sensor nodes act as signposts for the robot to follow [22]. In [23] the authors choose to discuss the similarities and the differences

between Ad-hoc networks and wireless sensor networks.

## IV. COMMUNICATION ISSUES IN SWARM ROBOTICS

### 4.1 Communication Range

for wireless networks in swarm robotic system, the communication range is strongly based on the power consumption, the more transmission range is the more power consumption, if a source node needs to communicate with a destination node, and the distance between them is more than the range of the source node, than multi-hop communication is required, even though short range transmission to the neighbor node is low power consumption, large number hops is also an issue as shown in figure 1.

In [24] an analytical model to investigate the optimal value of the radio transmission range is proposed for wireless ad hoc networks. The work investigated the applicability of the optimal per-hop transmission range that derived to the situation where the energy efficiency of the entire path from the originating source node to the final destination is considered. A distributed position-based self-reconfigurable network protocol that minimizes energy consumption was proposed in [25]. It was shown that the proposed protocol can stay close to the minimum energy solution when it is applied to mobile networks. Based on the application and the environment the developer can choose the transceiver to be used on the robot platform, if the range is not enough to cover the concerned area, multi-hop communication is an option.

### 4.2 Communication Topology

The best topology for any swarm system is mobile ad hoc networks as the topology may change at any time due to the mobility of the robots.

### 4.3 Bandwidth

When the robots employed to transmit high data rate as a video stream, then Wi-Fi is required, with the a drawback of power consuming, which means the battery of the mobile robots will be discharged quickly

### 4.4 Environment

The communication depends on the type of environment the robots will be used for, like on the ground, underwater or flying robots.
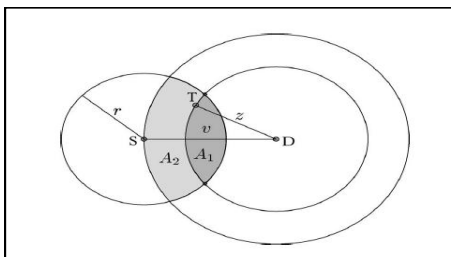


Fig. 1 Schematic representation of communication between two nodes in WSN [23].

### 4.5 Length of Message

any communication protocol contains header information that is sent with all the messages, so robots should be programmed to exchange short messages as much as possible.

### 4.6 Traffic redundancy

This problem in cooperative behavior of swarm robots is needed to be studied. The change of the communication frequency in a swarm system will affect the performance of the system, however individuals with high frequency will increase the overhead time, complexity and may lead to network congestion. Individuals with low frequency may reduce traffic and overhead of the network but it may lead to other problems like collision among individuals and partition the swarm.

### 4.7 Interferences

Interference or noise could be produced from nearby wireless connections, the sunlight or things like the infrared port of a laptop or even some metal surfaces or any electric devices that produce magnetic field.

### 4.8 Mobile Communication

Mobile nodes are more complicated than fixed nodes when advanced protocols for mobility are employed.

### 4.9 Number of Robots in a Swarm

As the number of individuals in swarm increase, the network overhead increase.

### 4.10 Security

To avoid an intruder from joining the swarm or receive the exchanged messages among robots, encryption algorithms can be used.

## V. CONCLUSION AND FUTURE WORK

Wireless communication in swarm robotics is the most important parameter, however all other parameters based on communication, choosing the communication system depends on the nature of the application, the environment and number of robots in swarm. When designing swarm robotics networks, the performance need to be evaluated according to the real requirements. Simulation programs were used in most of the mentioned papers and applying some of the proposed communication algorithms in practical is needed.

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