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An Optimal Graph based ZigBee Mesh for Smart Homes

Shanmuk Srinivas Amiripalli[1,2*] and Veeramallu Bobba[1,3]
[1]K L University, Guntur, AP, India, 522 502
[2]GITAM University, Visakhapatnam, AP, India, 530 045
[3]TKR Collage of Engineering & Technology, Hyderabad, India, 500 097

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The usages of IoT devices are increasing exponentially since a decade. To manage all these devices new technologies like ZigBee, 6Lowpan, LoRa etc., are available in the industry. ZigBee is popular among them which are mainly used for home automation systems. Star, cluster tree, mesh supports topologies in ZigBee. These topologies may not fulfill the requirement in improving Quality of service in design of smart home applications. To address this problem a simple, scalable, survivable graph-based topology named as TGO topology is proposed. Implementation can be performed in three phases deployment of sensors, basic topology formation and network formation. For the proposed topology, experiments were conducted on various qualities of service parameters like battery level, power consumption, bandwidth, throughput, capacity, network life time etc. by using cupcarbon simulator.

Keywords: Smart Homes, Trimet Graph, Optimization, ZigBee, Cupcarbon simulator, Smart cities, IoT

Introduction

ZigBee is a protocol on Low Rate Wireless Personal Area Network (LR-WPAN) having an IEEE 802.15.4 standard.[1] The range of this technology was around a distance of 10–75 meter and also varies from RF environment and output power. The major advantage of ZigBee is that it can operate easily for short distances. It can support low cost, scalable, stable, network. ZigBee has three topologies. They are the star, cluster tree, mesh.[2] The IEEE 802.15.4 has three main operation modes in their devices and major components are PAN Coordinator, Coordinator, and End Device. ZigBee is one of the best and most widely used Technology for smart homes.[3] It is generating a wide range of devices for smart homes for monitoring, managing energy and security. Cupcarbon is an IoT, smart city based WSN simulator. The main agenda of this simulator is to design, visualize, and debug algorithms. By using these different environmental scenarios were explained visually from basic to advance concepts from academic to scientific research. This simulator is mainly suitable for testing various wireless topologies, protocols, etc. The paper is organized as follows. In next section author present mathematical model followed by proposed approach and TGO mesh, and results are provided in last section.

Mathematical Graph Models

The usage of the topologies is increasing nowadays for solving many engineering problems in designing different applications.[4] The basics for these topologies are derived from graph theory a branch of mathematics. In this paper, our main focus is on studying centralized graphs like star, semi complete, trimet, wheel and complete graphs. Whereas star is 1 edge survivable, trimet is 2 edge survivable, wheel and semi complete is 3 edge survivable and complete graph is n edge survivable.

Wheel graph

In the wheel graph theory G= (V, E), Wn is formed by connecting a single vertex to all vertices of a cycle.

The Properties of wheel are vertices (V), edges (2n-1), girth (3), and chromatic number (3 or 4). Advantages of wheel graph are that it is less complex, low Cost, and demand medium maintenance. As Number of Nodes increases edge ratio increases largely and. Even after removing any 3-edges from a wheel graph the graph is still connected which is 3 edge survivable.

Semi-Complete graph

A Graph G1 is said to be semi-complete if it holds the properties of simple and for any 02 vertices u1,

*Author for Correspondence
E-mail: shanmuk39@gmail.com

v1 of G there is a vertex w of G1 such that w1 is adjacent to both u1 and v1 (in G) (i.e., Fu; w; VG is a path in G). K2 is complete, but not semi-complete. K1 is trivially semi-complete. To avoid trivialities, throughout this paper we consider a nontrivial graph, with at least three vertices. Properties of semi-complet graph are as follows 1. Any semi-complete graph is non-trivial2.Any semi-complete graph G is connected and hence contains spanning tree. Any edge of a semi-complete graph G lies in a triangle (cycle) and hence the graph has no cut edges, and so the graph is a block. 3. Any vertex of a semi-complete graph G lies in a triangle and hence the degree of each vertex is at least 2. So the graph has no pendant vertices. 4. Any Complete graph is semi-complete, but any semi-complete is not complete graph.

Complete graph

Let G = (V, E) the complete graph. Kn is formed by simple undirected graph and every pair of distinct vertices are connected with unique edges. Its properties are vertices (n), edges (n (n – 1) / 2), radius and diameter (0, 1), chromatic number (n).

Trimet graph

It is simply connected and planar graph.[5] One vertex called dominant vertex with the degree (V-1). Other (V-1) number of vertices with degree 2 and (3V-3)/2 Number of edges if V is odd. One more vertex called Special Vertex with degree 3, other (V-2) number of hanging vertices with degree 2 and (3V-2) /2 numbers of edges if V is even. Advantages of Trimet graph are less complex, low cost, maintenance is simple and 2 edge survivable. Properties of Trimet graph are minimum path distance of an Even GTEven TRIMET (n, (3n-2) /2) and GTOdd (n, (3n-3)/2) is 1. GTEven and GTOdd are even and odd TRIMET respectively satisfies the Euler characteristic (χ) = (R – E+ V) must equal to 2. Where R is the number of regions, E is the number of edges, and V is the number of vertices. GTEven (n, (3n-2)/2) is 3 vertex colorable, (n-1) edge and 3 region colorable. Todd (n, (3n-3) /2) is 3 vertex colorable, (n-1) edge and 2 region colorable.

Proposed Methodology

In the proposed model a novel optimal graph based TGO mesh was designed.[6] The design model was made up of combination of basic graphs mentioned in mathematical model. The proposed mesh model was simple, scalable, secure and survivable. It is an optimized mesh of complete mesh.[7] Formation of TGO mesh was explained by using flowchart which is at Figs 1 and 2 formation of TGO mesh in cupcarbon simulator was generated.

Devices used in Network formation

- **ZigBee Coordinator (Receiver)**

Receiver or coordinator is responsible for forming and maintaining of network. In a network only one coordinator is allowed and it can route the messages. Coordinator has to maintain security.

- **ZigBee End Device (Transmitter)**

Transmitter is responsible for requesting messages from receiver. These devices are movable and cannot route traffic but it can operate in sleep mode for better battery life.

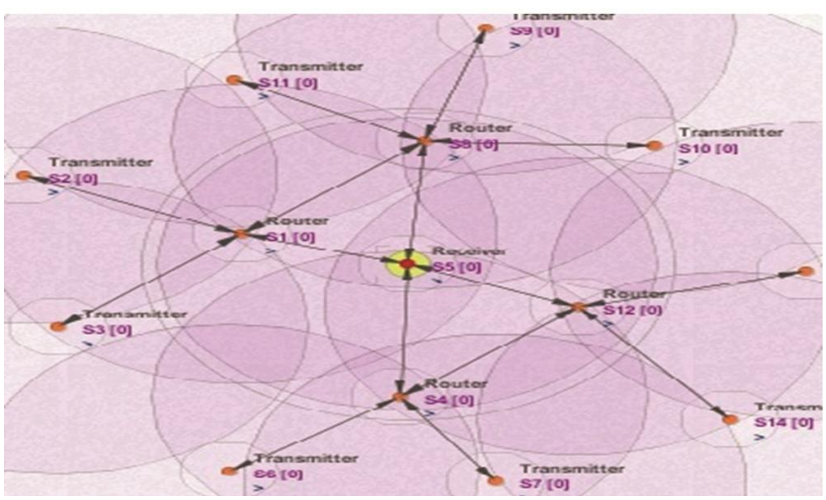

Fig. 1 — TGO Mesh formation in cup carbon

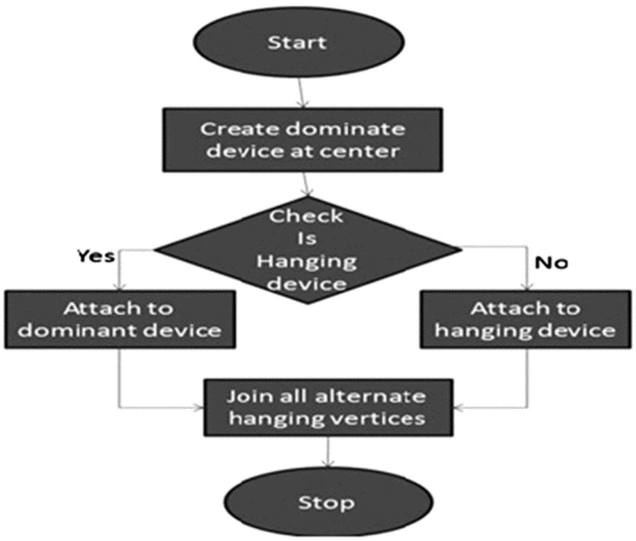

Fig. 2 — Flow chart for TGO Mesh Formation

- **ZigBee Router (Router)**

Router is responsible for routing messages with in a network and it can receive and store messages. It acts as a gate keeper in a network and allows new nodes to join in a network.[8]

TGO Mesh Formation

This model starts with explaining terminology used in TGO formation, Dominant device is Centre coordinator, Hanging devices are Routers, and Leaf devices are End devices. The creation of a dominant device which is located at the center and then all hanging devices are connected to the dominating device, at this point the resultant structure is star topology. To create a proposed design, join all alternate hanging devices. Then a basic topology will be formed with hanging and dominant devices. In final stage of mesh formation all leaf devices are connected to hanging devices which results to TGO mesh.[9] **Notations:** N_k for Network, S_m for Star Mesh, T_m for TGO Mesh, W_m for Wheel Mesh, K_{scm} for Semi-complete Mesh, K_{cm} for Complete Mesh, R_c for Receiver, R_u for Router T_r for Transmitter H_x for Hexagon topology.

Algorithm for proposed models

- Start
- Deployment of Rc at the center of a network which act as a sink.
- Deploy and connect all Ru to Rc.
- Number of Tr connected to each Ru will be obtained from count= (Tr/ Ru)
- Select network to be generated from Nk
- If (Nk== Sm) Connect Tr to Ru
- Else if (Nk==Tm) join alternate edges of Ru and Connect Tr to Ru.
- Else if (Nk==We) join all outer edges of Ru and Connect Tr to Ru.
- Else if (Nk== Kscm) join all outer edges and some inner edges of Ru and Connect Tr to Ru.
- Else if (Nk== Kcm) join all outer edges and all inner edges of Ru and Connect Tr to Ru.
- Stop

Implementation Details

In proposed topology formation, input devices are different sensors like receiver (R_c), router (R_u) and transmitter (T_r). Initiation of network formations was started at deployment of R_c at the middle of the network. In the next phase all R_u are connected to R_c forming a star, which is common structure for all five networks. Based on required output, networks connections were established on router and transmitter. Number of receivers added to each router was obtain by counting generator from number of transmitter divided by routers. Star, TGO, wheel, semi complete, complete meshes are generated as output.

Results

In this phase, experiments are conducted using cupcarbon simulator. Results are generated by fixing following parameters.

Simulation parameters: - time 8640s, speed 150ms, arrow speed 50 ms.

Radio parameters: - standard 802.15.4.

Device parameters: - sensor radius 20, energy max 19460, UART/Rate 9600.

In this research, TGO mesh was compared with different mesh structures to measure QoS parameters like battery level and power consumption at receiver, routers and transmitters' side after conducting several experiments on various quality of service parameters by NS2, Cooja and cupcarbon simulators the following results is derived. Power Consumption of TGO Mesh with other meshes are compared in Fig. 3. star and TGO has less power consumption because TGO is an incremental model for star. But in Table 1 star was not compared because it is not belongs to mesh family. It was observed that the power consumption of star, TGO is lesser than wheel,

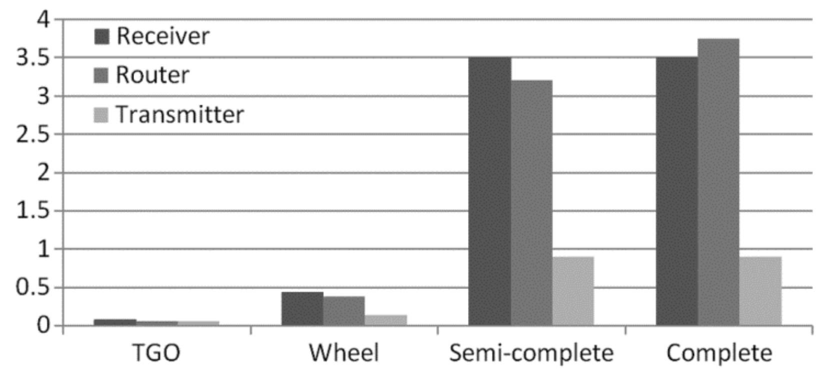

Fig. 3 — Comparison of Power Consumption of TGO Mesh with other meshes

Table 1 — Comparison of Power Consumptions

Devices/models	TGO	Wheel	Semi-complete	Complete
Receiver	0.075	0.44	3.5	3.5
Router	0.06	0.375	3.2	3.75
Transmitter	0.06	0.137	0.9	0.9

semi-complete and complete meshes. Power consumption by semi-compete and complete mesh is almost equal and high because as the number of devises or nodes increases the connections or edges will also increase drastically. TGO meshes are optimal mesh because of less number of edges or connections. Similarly, battery consumption of TGO is less than the other meshes because of less power consumption. Bandwidth, capacity and throughput are high for complete, semi-complete meshes, moderate for TGO, wheel meshes and low for TGO mesh. Network life time is long for TGO, moderate for wheel and less life time for semi-complete, complete meshes. Flow of duplicate messages in a network is less for TGO meshes, medium for wheel, semi-complete and more for complete mesh. Simplified results are tabulated after conducting experiments with different time modes.

Conclusion

Increasing the quality of service in smart homes is a major design issue. There are many ways to solve these problems by game theory, optimization techniques, soft computing etc. In this research, we have addressed above problems by using graph theory. The design goal of proposed mesh is to improve the Quality of service in design of smart homes. ZigBee uses star topology for home automation, and mesh for industrial automation. The proposed TGO mesh was designed for both home and industrial automation after careful observation of different mathematical graph models like Trimet, wheel, and complete graphs. Simulators used in designing and comparing TGO mesh with other partial meshes of ZigBee technology was cupcarbon, Cooja. Major part of comparison was done with cupcarbon simulator. The proposed topology was applied on fourteen devices with time 8640s, speed 150ms, and arrow speed 50 ms, standard 802.15.4, sensor radius 20, and energy max 19460, UART/Rate 9600. After careful investigation of power consumption at coordinator, routers, and end devices, it was noticed that power and battery consumption of TGO was very low when compared to wheel, semi-complete and complete meshes. Finally, an optimal mesh for smart homes and industrial applications was designed as a research contribution.

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