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An Unconventional Routing Method using Particle Swarm Optimization for the Internet of Things

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***Abstract:** The study introduces novel analytical modeling of a multipath fault-tolerant routing approach where the design principle is formulated based on a bio-inspired optimization modeling of swarm optimization principles. The prime objective of this novel approach is to deal with network failures of Internet-of-Things (IoT) in a faster manner and recover the network operations as early as possible without compromising much energy. This way, the network becomes more reliable and sustainable even if any events occur that make the senor node functionally disabled and even if any types of path failures take place, regardless of energy consumption factors in IoT routing scenarios. However, the approach also capable of handling energy problems during the IoT routing scenario to a significant extent. Further, the outcome of the study shows that the fault-tolerance routing approach based on unconventional particle swarm optimization (FT-PSO) attains better results as compared to the existing baselines.*

***Keywords:** Multipath-routing, Particle swarm optimization, Fault-tolerance routing, Internet of Things.*

I. INTRODUCTION

The direction of research evolution in the area of wireless sensor networks (WSN) for a decade envisioned for a better sustainable approach towards making Internet-of-Things as a reliable service to fulfill a variety of consumer requirements in practice. WSN in real-sense forms a foundation for future generation IoT architecture where a set of interconnected heterogeneous objects i.e., mostly consumer electronics products with various operational conditions, communicate with each other in a complex mode of interactions. The notion of IoT is planned as an infrastructural backbone to fulfill the requirement of services for the future generation cellular networks like 5G and others. This type of network implements faster data transfer rates within a constrained environment where IoT applications cannot compromise with the delay in service delivery execution [1].In the context of IoT communication, the components function in a way where a set of configurable or programmable objects exchange data between each other or with the people in the same.

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To make the IoT services sustainable for a variety of on-demand applications and also to fulfill the requirements on time, the routing process has to be fault-tolerant, which in longer run assure maximum connectivity among the people and objects in IoT environment [2][3]. However, it is mostly observed that IoT devices, in reality, shrouded with energy problems, which creates a bottleneck condition towards enhancement of fault-tolerant routing as it has to adhere to the energy resource availability factor. Various studies claim- the emergence of application requirements in IoT services such as healthcare, smart city, etc. which need to have fault-tolerant capability defined during the routing to make the operations more reliable with sustainable throughput enhancement capabilities. Thereby emphasize has been laid since many years towards improving the fault-tolerant capability in IoT with better routing scenario from the view-point of data delivery modelings. The operational IoT environment makes sensor nodes to function in an autonomous way in an uncontrolled scenario where manual intervention of human administration is not advised. In the case of sensor network operational environment- it is mostly observed that the available energy resources for the purpose of communication differ from the amount of energy required for computation purpose. Which means that available energy for communication is very less which is significantly higher in the case of computational requirements and practices? Thereby it is essential to develop a fault-tolerant (FL) routing protocol and algorithm which is sensor-driven and can operate with a limited amount of communication energy irrespective of any computation energy. And it also should be capable of retaining the routing operations, if unpredictable events like intermittent link breakage, node damage or any other types of path failure occur due to packet dropping in intermediate hops without having any effect to the performance factors of the network. This way network reliability can be increased and also network functionality from the view-point of quality of services (QoS) can be maximized [5] [6] [7]. Multipath routing is a highly adopted approach to deal with network failure scenarios, but the challenge in the existing system arises to handle the performance trade-off between energy and routing efficiency for any type of sensor-driven IoT environment and applications. Hence the multi-objective problem (MOP) comes under the optimization modeling and solution [8] [9]. The study thereby conceptualizes the fault-tolerance routing approach based on unconventional particle swarm optimization (FT-PSO), which provides a minimal computational effort to deal with the system/path failures within an IoT networking scenario.

The faster computation of FT-PSO can recover the network operations even if any fault occurs during the routing scenario.

It leads to balance the performance trade-off in terms of delay, throughput, and energy consumption. The study also performs an extensive numerical analysis, which demonstrates that the proposed FT-PSO outperforms the conventional baselines in terms of both energy efficient fault-tolerant routing and does not compromise the throughput factors. The overall structure of the manuscript is patterned as follows: (section-II) further illustrates the existing review of literates, which also shares a similar goal to deal with the fault-tolerance problems in the context of IoT and heterogeneous WSNs. It also exhibits the design limitations of existing hierarchical multipath routing solutions while integrated with MOP (section-III). Further, the proposed design approach with the analytical notion is illustrated in the (section-IV) followed by implementation outcome in (section-V). Finally, (section-VI) concludes the overall research contributions.

II. LITERATURE SURVEY

The on-demand routing with fault-tolerant capability in the context of WSN gained lots of attention from the researchers in the past, and in the area of IoT as services also fault-tolerant features are yet to be explored more broadly. The study of Hasan et al. [10] has paved the path to explore various fault-tolerant routing problems in IoT. It outlines an extensive review to generalize the background of the problems associated with multipath routing problems, which negatively influence the Quality of Services (QoS) factors in real-time multimedia WSN [10]. There are several studies in existence that show that multipath routing has a better scope to deal with the network faults with significant tolerance capability even if any unpredictable scenario results in device malfunctioning, network partitioning, etc. Hadjidj et al. [11] introduces a novel multipath routing approach which intends to handle the network failures with better FL capabilities for heterogeneous wireless networking scenarios. The approach basically increases the construction of routing paths during each communication round also applies energy-node-disjointness paradigm to deal with the network faults which in longer run found quite effective to retain higher degree of QoS factors along with considerable throughput performance [11]. The fault-tolerant routing problem in many studies formulated as MOP, which is also subjected to as a set of constraints. The approaches of Akbas et al [12] and Jiang [13] also addresses the problem in existing fault-tolerance routing mechanisms and also suggested that optimization can be a prime solution to overcome the memory and computation problems in IoT based networking operations. The study of Hu et al.[14] also suggested that PSO is a good solution to overcome this problem of existing multipath routings for fault tolerance [14]. It also shows that it can significantly increase the routing performance with an added advantage of resource availability at any time, reliability, and consequent independence in the network. The authors in Liang and Suganthan [15], Al-Turjman [16], Azharuddin et al. [17], Pant et al. [18] and Shieh et al. [19] also suggested PSO as an optimal approach to enhance the fault-tolerance and cluster-lifetime in the context of IoT. The next section arrives in outlining the research gap, which is needed to be addressed in this proposed solution design.

III. RESEARCH PROBLEM IN BRIEF

The analysis of traditional approaches of hierarchical fault-tolerance routing reveals the fact that most of the techniques are computationally expensive and do not considers the energy factors into consideration while dealing with throughput and delay factors. Whereas, although PSO based solutions are advised to deal with network failures in emergencies but still most of the approaches are not much energy efficient and do not ensure faster recovery of route components from the perspective of IoT Hemavathi P and A.N. Nandakumar [20]. Thereby an optimized multipath fault-tolerant routing approach is needed to be developed to deal with network performance and energy aspects in IoT.

IV. FT-PSO: DESIGN APPROACH

The formulated system introduces a novel concept that targets to optimize the multipath routing performance with higher efficient fault-tolerance capability in the context of IoT. The design approach is built from the perspective of analytical methodology, where the prime emphasis given towards implementing the fault-tolerant mechanism in a way where it can balance the performance and cost aspect of a two-tier IoT environment. The following figure 1 shows an overview of the block-based architecture that is intended to represent the work-flow of FT-PSO from a very theoretical view-point. The system applies a novel bio-inspired PSO based multi-tier routing for IoT in order to attain better route recovery if any event of route failure or node damage takes place.

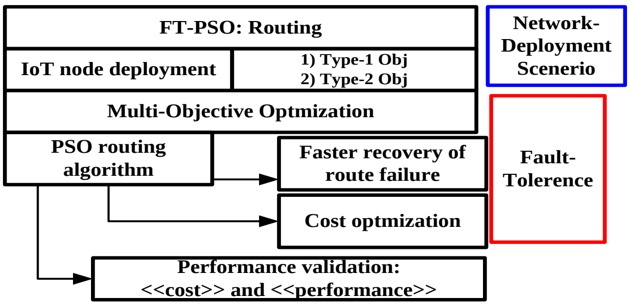

Figure 1 FT-PSO: Block-based schematic Design

The system is designed from the view-point of MOP, where the solution model incorporates novel fault-tolerance modeling subjected to perform split-proof disjoint manner of multipath routing dis(r) with a higher degree of connectivity establishment.

A. IoT network deployment

The system is designed from the philosophy of mix-mode deployment of IoT obj here obj represents $Obj = \{t1, t2\}$ for two different levels.

The systems also employ complex network representation with graph-based modeling to represent the connectivity measures.

The entire population of nodes is represented in the form of swarm topological structure and further subjected with an algorithm to perform a multipath routing scenario to balance the trade-off between fault tolerance and communication overhead. Here in the case of node deployment, t1` represents a type-1 node, which is rich in terms of resources like energy availability, communication, and computation capabilities, whereas t2 represents the node with comparatively lower computational efficiency.

B. Optimization Modeling

The notion of dis(r) is formed in a way where the faster topology control and resource utilization taken place in order to assist in fault-tolerance during multipath routing in IoT. The notion of network and data aggregation between IoT nodes is designed in a pattern of many-to-one with maximum levels of connectivity constructions based on on-demand requirements, as shown in the following figure 2.

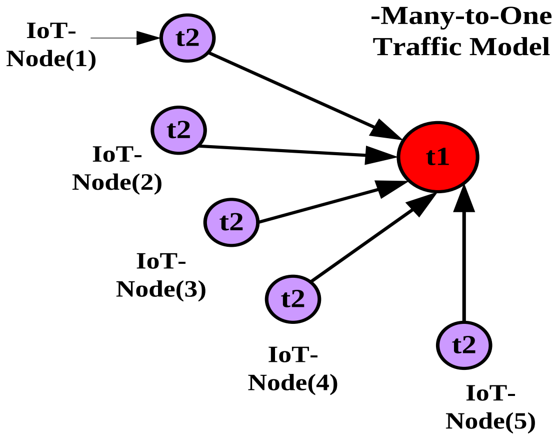

Figure 2 Many-to-one traffic pattern with optimal connectivity using Graph modeling

The optimization (MOP) modeling also considers designing a module that can accomplish a higher degree of fault-tolerance capability with the very lower cost of energy and other functional operations in the context of IoT. The FT model is designed based on two different prime factors, such as coverage, connectivity, and sensor node damage factor.

i) FT modeling based on Connectivity Graph

The coverage modeling for connectivity graph orientation is represented based on the principle of the Markovian model with a function g_1(X): *c* (t1, t2); it means that the sensor device is malfunctioning should get diagnosed and replaced by another suitable sensor node. The coverage modeling of g_1(X): *c* (t1, t2) can be computed as follows:

$$g_1(x){:}c(t1,t2) \leftarrow g(k,t1,t2) - f(c,t1,t2) \text{ eq. (1)}$$

Here g(k) represents the probability factor of accuracy in detection of the false-positive case in detecting and rejecting the sensor nodes (sn), which are malfunctioning. On the other hand, f(c) represents the probability factor that indicates the ineffective replacement of faulty sn.

ii) Sensor node damage factor

The sensor node damage factor is also estimated, and a model based on the notion of distribution approximation is applied to estimate the failure rate associated with sensor damaged factor. That can be represented with the following mathematical schema.

$$\varepsilon(\Delta,\rho) = 1 - e^{(-\Delta*\rho)} \text{ eq. (2)}$$

Where $\rho = -\left(\frac{1}{\Delta}\right)\log\left(1 - \varepsilon(\Delta)\right)$

The eq.(2) indicates the probability factor ε , which indicates the cumulative estimation of how many sensor nodes are malfunctioning or do not pose operable conditions to be specific over the time specified for Δ. The multi-objective optimization modeling targets to $Min \rightarrow QoS\{d\},E$ $Max \rightarrow QoS\{Th\}$ and, where d denotes the delay factor. E denotes energy requirement, and on the other hand, Th denotes the throughput factor, which is maximized by the notion of dis(r). The optimized PSO based routing scenario is illustrated with the following algorithm working flow:

Algo: FT-PSO routing
Input: Number of IoT devices: t1, t2
Output: FT with maximized Th and Minimized Delay
Start
1. IoT network deployment: Mix-mode
2. Enable dis(r): To ensure that an IoT node remains connected to the sink even in the network failure.
3. FT modeling with eq.(1) and Eq. (2)
4. Optimization Objective: MOP
5. Apply optimized Particle Swarm Optimization to ensure better dis(r) with
Personal-best and global-best *sol* [exchange of data-packets improve the *sol*]
6. Optimize the velocity factor to improve fault-tolerant multipath routing schema
7. Compute fitness function: fit()
8. Converge towards the best possible solution of optimal route establishment.
9. $Min \rightarrow QoS\{d\},E$

The algorithm highlighted above shows how the FT-PSO optimizes the routing performance with the assurance of a higher degree of connectivity and also handles network failure with better fault tolerance schema. It also ensures optimal convergence solution depending upon the exchange of data packets in between nodes within finite steps of iteration. The next section appears to be discussing the experimental outcome obtained by simulating FT-PSO in a numerical computing environment. It also compares the outcome with the most frequently adopted baseline model where hierarchical routing is designed and meant for fault tolerance capability.

V. FT-PSO: NUMERICAL OUTCOME

The analytical design and modeling of FT-PSO are numerically constructed to represent the IoT networking environment and multipath routing operations. The maximum number of hop-count is defined within the range of 5. The following the operational parameters which are exclusively considered to construct the modeling of FT-PSO from the view-point of the numerical approach, as shown in the following table 1.

Table 1 Simulation operational parameters and considered numerical values

Operational parameters	Numerical value
The energy required for sensor electronics circuit	60nJ/bit
Topological pattern	Uniform distributed random
Amplification energy	0.00234 J/bitm^2
Transmission data rate	220 kbps
Personal best coefficient: (Q1)	3.4
Global best coefficient: (Q2)	2.1
Hop-count	3-5

The following figures show the comparative outcomes of the study in terms of delay and throughput analysis.

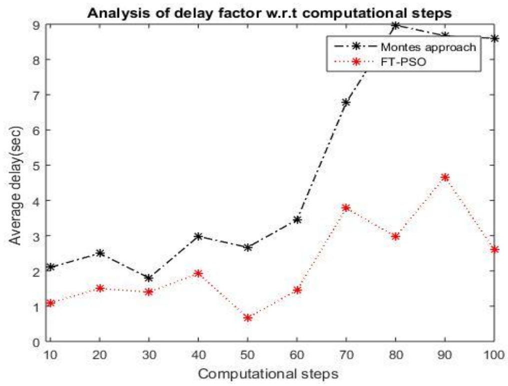

Figure 3 Numerical Analysis of Average Delay

Figure 3 clearly shows that FT-PSO attains better significantly lesser delay as compared to the Montes approach; Montes et al. [21] for the computational steps range from 10 to 100. The following table further exhibits the statistics of the corresponding values obtained for FT-PSO in the context of average delay computation.

Table 2 Quantified Statistics of the numerical values corresponding to FT-PSO

	Computational steps	Average delay (sec)
Min	10	1.8
Max	100	8.97
Mean	55	4.852
Median	55	3.215
Mode	10	1.8
Std	30.28	3.018
Range	90	7.17

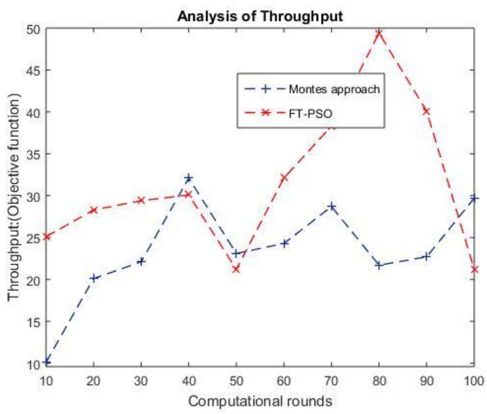

Figure 4 Numerical Analysis of Average Throughput factor

The outcome of the figure 4 shows that as compared to the existing baseline the formulated approach attain better and consistent throughput performance through the fault-tolerant multipath routing and the incorporation of PSO enabled dis(r) ensured maximum connectivity factor which minimizes the chances of packet drops and also increases the reliability of the network performance with satisfactory QoS factors.

Table 2 Quantified Statistics of the numerical values corresponding to FT-PSO

	Computational steps	Average delay (sec)
Min	10	21.2
Max	100	49.4
Mean	55	31.52
Median	55	29.75
Mode	10	21.2
Std	30.28	8.886
Range	90	28.2

VI. CONCLUSION

The study introduces a novel approach of multipath routing, which ensures better fault-tolerance capabilities for the IoT environment with optimal convergence solution. The paper introduces a novel concept of FT-PSO, which applies PSO based optimization solutions to deal with network failure, and it also ensures faster recovery of network components if any sensor node damage or route failure takes place so that the QoS requirements within a specified interval of time can be satisfied. The outcome of the study shows it accomplishes a higher degree of throughput and also at the same time handles delay and energy constraints.

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