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Optimized Routing Technique for Adaptive Data Transmission in Industrial IoT

Shreyas J, Kavitha B, Udayaprasad P K, Dilip Kumar S M
Dept. of Computer Science and Engineering, University Visvesvaraya College of Engineering, Bangalore, India

***Abstract*—In recent years, industrial internet of things (IIoT) has become an important research topic among industry and academia. In IIoT there is a huge demand for data exchange among different smart devices with different delay flows. However, there is a less amount of research has been carried out in this field. In order to address the limitations of the traditional routing method, The proposed work gives a numerical modeling applicable to perform adaptive transmission optimization with a set of the programmable module structure and ensure cost-effective route establishment. The proposed work utilizes bio inspired swarm intelligence based data-driven cluster head (CH) selection with energy optimized route formation to obtain an optimal route. The extensive simulation outcome shows that particle swarm optimization (PSO) based clustering attain better delay, path difference degree and packet delivery ratio as compared to other conventional methods.**

***Index Terms*—Adaptive Data Transmission Path, Industrial Internet of Things, Particle Swarm Optimization, Swarm Intelligence.**

I. Introduction

The current advancement in wireless communication standards has made industrial wireless networks (IWNs) [1], internet of things (IoT) and artificial intelligence [2] potentially stronger. The wide range of industry-oriented applications in IIoT requires a higher degree of information flow control with respect to different delay constraints.

The smart manufacturing currently involve exchange of different types of data among different devices, machines, and users. The heterogeneous data flows at different level makes the routing crucial in the context of IIoT communication and networking operations.

The clustered and group-based IIoT provides preliminary basis of communication but it lacks effectiveness during routing. The conventional data routing technologies do not emphasize more on reliability where, the delay factors are essential. To overcome from these limitations The study mainly introduces a joint framework which incorporates two-tier processing of a routing schema- In the first level of routing processing the computational flow checks whether any ordinary data stream is latency constrained or not, if the priority value is ensured then it applies a specific routing to meet the time constrains in IIoT options. However, in case of newly emerged data processing and routing, the proposed system applies an adaptive data transmission algorithm strategy, to obtain cost effective data transmission with low-latency routing [3]. The study proposes a particle swarm optimization schema to address this problem along with mathematically derived numerical computation. Finally the outcome of the experiment shows that the formulated model accomplishes better outcome in contrast with the existing techniques.

The contributions of the paper includes:

1) A software defined network architecture with edge computing for IIoT is proposed to facilitate the management of less communication resources.
2) An efficient adaptive data transmission routing method is proposed by categorizing the data in to low prioritized and high prioritized data according latency constraints of data.
3) The proposed work integrates bio inspired particle swarm optimization algorithm to get energy optimized route formation.
4) The performance of the proposed work is evaluated by comparing against conventional methods in MATLAB simulation platform.

The remaining section of the paper is organized as follows. Initially section II discusses an overview of related work which addresses all the major research work being done in this area. Then in section III problem statement of proposed methodology is presented. Later in section IV proposed methodology and followed by research methodology has been explained Section V. Section VI discusses about performance analysis and finally in section VII concluding remarks has been presented.

II. RELATED WORKS

SDN plays a prominent role in the establishing of robust and efficient smart IoT environment. The conventional SDN based solutions were mainly focused on physical level configuration. At present, more research study investigating various SDN based approaches for efficient data transmission with high speed bandwidth and low cost with minimum energy consumption. Therefore, OpenFlow SDN model is proposed as a important communication network architecture which includes three layers viz; Infrastructure layer, control plane and Application layer. The work carried out in [4] have used Open flow SDN technology and proposed a SDN based WSN architecture which support the application specific requirements like IoT. The proposed SDN architecture include SDN controller, device and network topology management. From the experimental analysis have show that the proposed SDN architecture is able to enhance the network performance in terms of packet transmission, energy optimization and data overhead.

Shreyas J: e-mail: (Corresponding Author: joseph.shreyas3@gmail.com).

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Minimum energy consumption is considered as most prominent performance parameter for any WSNs as well as IoT applications. Liu et.al [5] have proposed A reliable and energy efficient data transmission with optimum routing protocol is introduced by for wireless networks. Also an optimal energy transmission, have derived the probability factor for encoding and decoding the data packet to attain the network coding gain. From the simulation results showed that, the proposed energy efficient routing protocol outperforms as compared to existing routing protocols with respect to minimum energy consumption. However, in the WSN environment the transmission of multimedia data is also considered as critical challenge because of data size, more energy consumption as well as bandwidth demand [6]. To solution this problem, Wang et.al [7] have utilized the cloud computing technology and introduced a video streaming model for mobile devices. The proposed model can provide the high quality video streaming by controlling the streaming bit rates based on the fluctuation of network quality. The objective was to validate how the transmission adaptability can improve at cloud platform and it helps for mobile users also.

In the design and development of large scale WSNs, deployment of sensor nodes, low powered and spectrum scarcity, automatic sensing capability becomes a key challenge to provide multiple real-time application for industrial IoT citesunitha2018nature. In such smart industrial environment with noise and interference, an enhanced co-operative spectrum sensing mechanism can provide efficient spectrum sharing among the primary and secondary users, and also solve the spectrum scarcity and energy consumption problems to build a smart IoT environment. The work in [8] have proposed a new spectrum sharing mechanism to solve the packet error and packet loss challenges. The study adopted mathematical modeling approach and formulated data transmission policies. The system probability and energy consumption rate was analyzed by measuring the bit error rate, packet loss and both. The simulation output showed that, the proposed data transmission model can improve the packet scheduling probability and optimize the energy consumption rate for co-operative spectrum sharing approach at different scenarios.

III. PROBLEM STATEMENT AND OBJECTIVES

The problem considered in the proposed work is to design an optimized routing technique for the adaptive data transmission in industrial internet of things with the following objectives:

1) To reduce the average delay.
2) To increase the packet delivery ratio.
3) To maintain better path difference degree (PDD).

IV. PROPOSED SYSTEM

The proposed work initially formulates analytical core modeling with software defined networking (SDN) component which enables edge computing (EC). The model numerically includes different latency constraints to model two different routing algorithms such as i) Algorithm to route normal or low priority data packets in low-deadline scenario, on the other hand it also designs another numerical modeling which incorporates low-latency data traffic management with ii) Algorithm to route highly prioritized data in high-deadline scenario. Finally, the entire system integrated with a swarm intelligence specifically particle swarm optimization based clustering to attain optimized communication performance in the context of SDN.
The traffic modeling considered a factor called degree of path difference ϕ_{PDD} which basically selects the cost-optimized route by balancing the traffic load and satisfying minimum energy constraints. The formulated adaptive SDN-assisted network architecture in the context of IIoT basically focuses on distributed management of data traffic in the presence of limited communication resources. It basically controls the data flow with a real-time decision analysis in the context of edge computing assisted SDN based IIoT for machine to machine (M2M) communications. The formulated system basically employs effective power control strategy which takes ϕ_{PDD} into consideration to suggest optimal multi-hop based route formation from source to destination in case any dynamic data flows. Irrespective of time consumption demands, the algorithms allocate necessary resources with a proper power control transmission strategy. The study realized the effectiveness of data transmission path/route (DTP) optimization for maximizing IoT networks throughput by incorporating multipath route discovery [9], [10], [11].

A. Deployment and set-up of network module

In this phase of development the proposed work defines a specific size of marker to highlight the bounded region for each grid and the location points where grids have to be placed. It is shown with the following mathematical notation. To make the grid deployment evenly spaced, the marker size is considered with (1 * 4) row vector which is a matrix $\vec{M} = [0\ 3.3\ 6.6\ 10]$ Here $L_B \leq 3.3 \leq H_B$ and $L_B \leq 6.6 \leq H_B$ and evenly spaced with value = 3.3 for the ease of implementation the next step of the execution flow is to generate random x and Y coordinate values which can be uniformly distributed over the deployed grid-based region. In the second phase of computation basically evaluates each header node or cluster head for individual grid as shown in the Fig. 1. In the third phase of computation the framework joins all the headers with their respective zonal nodes and the connectivity among them get established with a graph theory. and finally in the IV phase, process establishes connectivity among the header/CH nodes as shown in Fig. 2.

B. low-deadline scenario

The Algorithm 1 is a part of the framework which intends to formulate optimized cost-effective route to handle the ordinary traffic scenario. The extensive execution flow of the algorithm shows that, it can handle the adaptive transmission well with very lesser fault occurrence. The reliable link establishment enhances the throughput and goodput by satisfying the delay constraints and also at the negligible cost of transmission. Fig. 3 highlights route establishment between a sender and receiver node using low deadline scenario where the study exclusively considers ordinary data packets.

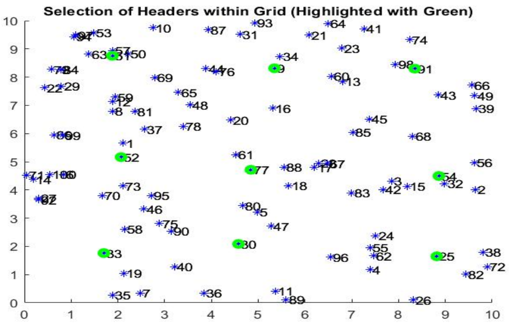

Fig. 1. selection of Headers within grid

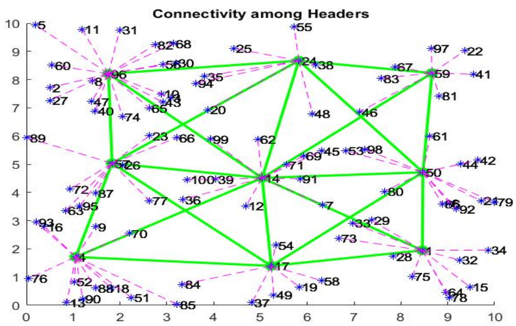

Fig. 2. A Connectivity establishment among adjacent headers

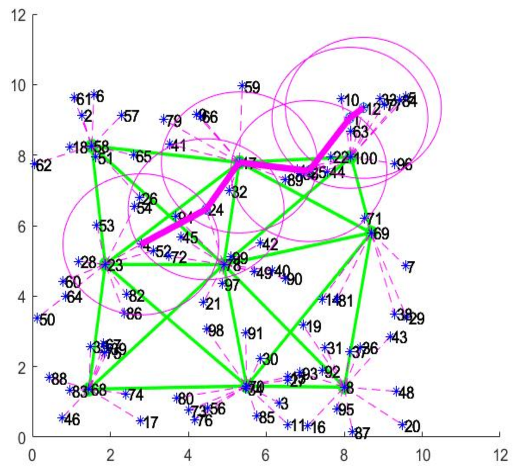

Fig. 3. Highlights route establishment between 1 sender and receiver node using low deadline scenario where packets the study exclusively considered ordinary data

C. *High-deadline scenario*

The proposed is numerically formulated and designed to handle the high-deadline situation where it mimics SDN assisted industrial internet of things (IIoT) communication with cost-effective paradigm. The computational flow of this algorithm is simplified and normalized with extensive numerical analysis. The relaying of data packets CHs /headers play a very crucial role which is defined by the SDN assisted component to ensure reliability of dataflow with fault control and lesser delay constraints. Fig. 4 highlights route establishment between a sender and receiver node using high deadline scenario where the proposed exclusively considered emergent data packets.

Algorithm 1 Proposed Algorithm and Design for Low dead Line Scenario

procedure
- Initialize $C_{range}MAX, r, CH_{acr}, n_{sende}rid, n_{recv}id$
- Repeat $\rightarrow$ Network set-up (Stage-1 to 4)
- Compute grids and the respective CH_i where i = 1 to 9.
- **for** `i ← 1:size((`$|\overrightarrow{x(l)}|$`)` **do**
  - `plot the network model`
- **end for**
- Invoke function to perform routing internally
- a) Adaptive Optimized Route Selection $\leftarrow$ $f_{sender}To_{receiver}2(n_{sender}id, n_{recv}id, |\overrightarrow{x(l)}|, |\overrightarrow{y(l)}|)$
- b) Find nodes which are within the vicinity region of the sender nodes
- c) Compute the node and their indexes which are within the range of sender
- d) Compute the Dist[] between sender and all other nodes
- **if** dist[] $<$ r **then**
  - Consider only the nodes with minimal dist[]
- **end if**
- Formulate Link[] , and select the closest node to the RecV[]
- Compute distance of the ranged nodes to the RecV[]
- Arrange and sorting of distance with respect to their idx.
- Formulate hop-by-hop connectivity among the selected nodes within range
- Apply time synchronization [t1 t2]‘

end procedure

D. *PSO scenario*

The proposed work incorporates swarm intelligence based clustering enabled routing to optimize the communication performance of SDN assisted IIoT. The PSO concept basically mimics the collective behaviour of swarm of particles to solve distributed clustering problem of IIoT where IoT nodes will be functionally sensor enabled. The architectural block based diagram of PSO based clustering is shown in Fig. 5.

The design of the proposed module in this phase formulates a PSO computation approach to evaluate the distributed computing paradigm in IIoT systems. As IIoT systems basically executes distributed computing paradigm where every node supposed to apply the similar execution flow of the above formulated PSO algorithm. This process is used for the most efficient cluster head (CH) selection. In every phase of communication with proper adjacent node discovery process, the computational execution structure of the formulated PSO approach is numerically optimized by satisfying the constraints of communication and execution. The approach is numerically

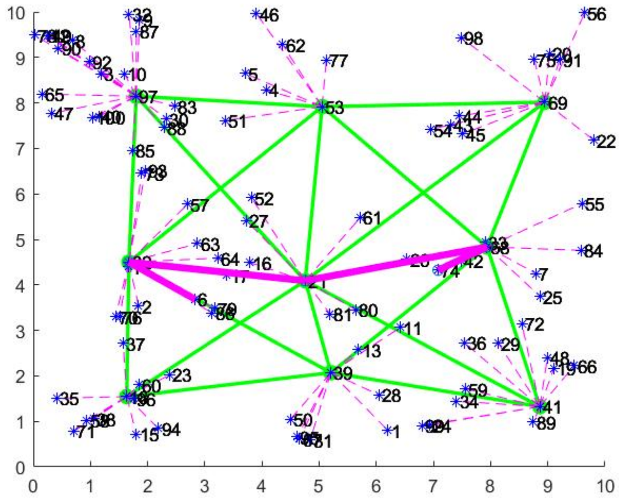

Fig. 4. Highlights route establishment between a sender and receiver node using high deadline scenario where packets the study exclusively considered emergent data packets.

designed in a way where it mimics the exact scenario of particle swarm optimization in more specific. The proposed PSO initially deploy the grid based topology matrix for the IIoT within a scaled region. Further it enables the distributed clustering approach in each node and with the desired process the algorithm initially established communication vector and ensure their neighbor nodes using neighbor discovery process. Once the process get completed, each IIoT node runs the algorithm execution process to determine the CH corresponding to each grid which also represents the group of IIoT member nodes during communication process. After selection of

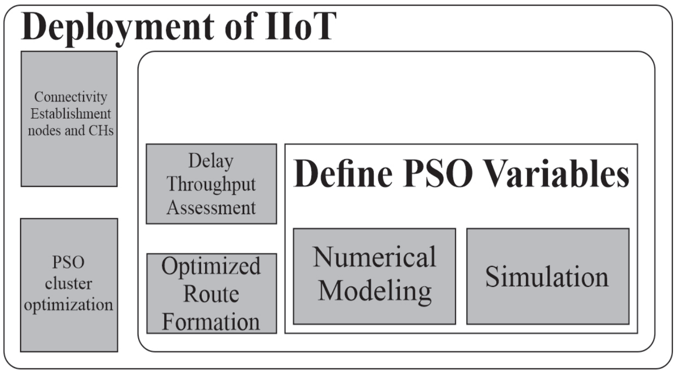

Fig. 5. Block-based overview of PSO based Clustering Schema

headers/CH, the connectivity takes place between nodes with a "connected graph" where IIoT nodes can reach to each other via connections or weighted paths. The process further localize base station/sink and also establish connectivity among the adjacent CHs and CHs to the sink.

The algorithm further initializes a set of PSO parameters which are conventional such as maximum iteration (maxIT), population size of swarm (nPoP) and other decision variables. Further it enables the formulated optimized PSO function which further assess communication rounds with estimating cost structure in terms of personal best and global best solutions which is mapped with energy and proximity metrics in this context. The cost optimization here assist to select the best possible CH in every grids or group of nodes which having optimal energy and also can ensure better energy management in the context of distance vectors. The CH updation and selection takes place in every round of communication stating from the data aggregation at CH from the data aggregation at sink. The collaborative communication with the involvement of communication and learning makes this system more intelligent and smarter to determine which possible CH will utilize energy with optimized cost. Finally 1st order radio energy modeling is used to assess the transmitter (Tx) and receiver (Rx) node energy and it computes the remaining energy of the entire system. This way the communication establishes best possible routes by selecting efficient CH at every instance of communication till the last node death. The outcome has further shows that this paradigm optimizes the cost of communication without compromising the energy performance.

V. PERFORMANCE ANALYSIS

This part of the proposed work basically discusses about the numerical outcome being accomplished after conducting the simulation for the formulated integrated modules. This assist in evaluating the performance of the formulated systems and validates its response curve. The performance validation has been considered with respect to a set of performance metrics such as average Time delay, degree of path difference, packet delivery ratio and finally good put and throughput. The proposed methods is compared with the existing methods such as shortest path node discovery (SPND) [12], shortest path among cluster heads node (SPCN) [13] and Cluster head maximum rate node (CR) [12]. Good put and throughput are basically refers to important performance metrics which actually expresses the rate of successful packet delivery through a wireless spectrum channel with limited bandwidth in IIoT.

A closer interpretation of the above Fig. 6 clearly shows that due to learning coefficients and optimized clustering parameters on the basis of local and global best solutions the proposed work exhibits lesser delay constraints satisfying energy modeling as compared to the conventional baseline models such as CR, SPCN, SPND and ATOP. It is also observed that ATOP also provide better outcome in the case of delay but not much better than the PSO based solution. It can be seen in both ATOP and PSO based clustering if the data amount (Mb) ranges from 100 to 900 but still the average delay comes below 2000 ms which is quite better and superior as compared to others.

The Fig. 7 and 8 shows that PDD amount is superior in the case of PSO based clustering and ATOP based adaptive transmission optimization, which ensures the reliable link formulation between source to destination with cost optimized route formation by satisfying the energy constraints. Overall interpretation basically shows that PSO based clustering outperforms other routing paradigm as it ranges between 0.5 to 1 in most of the cases.

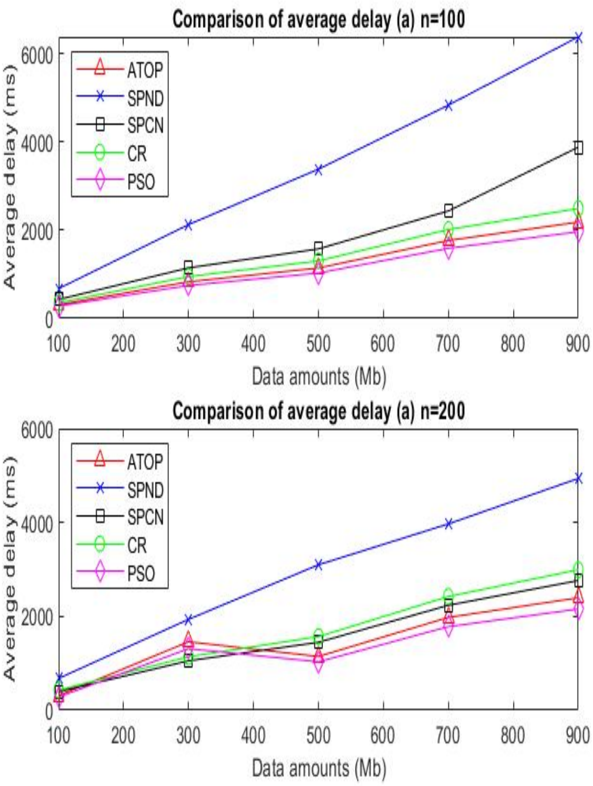

Fig. 6. Analysis of Remaining Average delay with number of node 100 and 200.

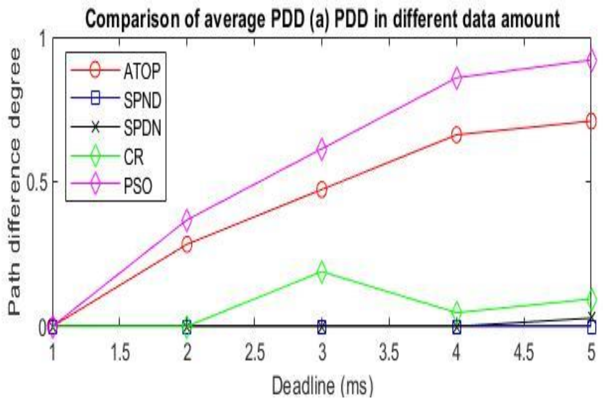

Fig. 7. Analysis of average degree of path difference (PDD) with different data amounts

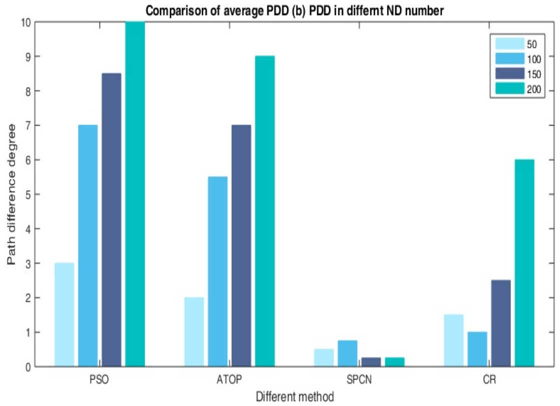

Fig. 8. Analysis of average degree of path difference (PDD) in different ND numbers

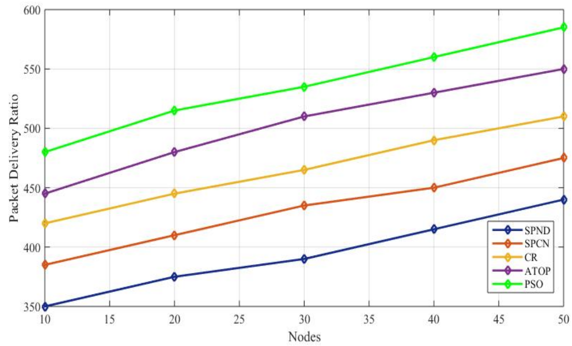

Fig. 9. Analysis of packet delivery ratio for 50 nodes.

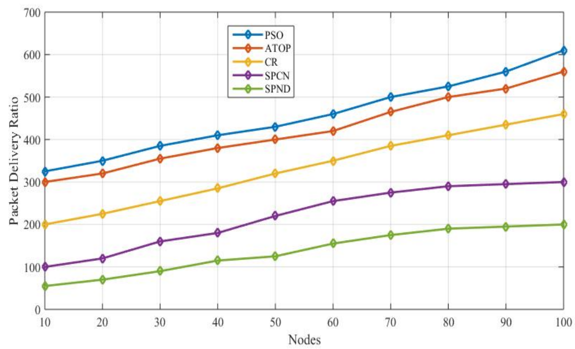

Fig. 10. Analysis of packet delivery ratio for 100 nodes.

The performance of the packet delivery ration with different nodes is given in Fig. 9 and 10. The packet delivery ratio is evaluated by considering packet delivery ration against the number of nodes. From the figures it can be observed that the proposed method outperforms better compared to CR, SPCN, SPND methods.

VI. CONCLUSION

The concept of IIoT basically remains as a foundation for the futuristic smart factory systems in the context of industry 4.0. Due to dynamic data flow and communication demands IIoT suffers from lack of performance when QoS aspects are considered. Thereby transmission strategies are needed to be optimized in a proper manner to handle the energy and performance trade-off. This study proposes an adaptive data transmission strategy which ensure cost effective route formation and which is adaptable to any dynamic traffic situation. Finally the proposed integrates the computational framework with a PSO modeling for energy optimized clustering in the context of IIoT. The promising outcome of the experiment shows that the formulated system accomplishes better outcome in terms of throughput, goodput, average delay in contrast with the existing methods.

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