IJCSN International Journal of Computer Science and Network, Volume 6, Issue 2, April 2017
ISSN (Online) : 2277-5420
www.IJCSN.org
Impact Factor: 1.5

Context Aware Retail Chain Management in Distributed Sensor Networks

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Abstract - Distributed Sensor Network(DSN) have attracted significant attention over the past few years due to growing list of many applications can employ DSNs. In all applications a large number of sensors are expected, requiring careful architecture and management of the network for increasing effectiveness of DSNs. The proposed system uses DSN for real-time tracking of the products in retail management. As a part of proposed system, many contexts derived in retail industry based on human perspective. At a basic level of design, sensors are deployed in each rack which provides the real time information about the products. This information can be used by warehouse manager/store manager for day to day activity in retail industry. So there is an acute need for smarter computing devices to reduce the burden on retail chains. R&D team can also use this information to understand consumer behavior. The proposed scheme is simulated using Castalia simulation tool, a derivative of OMNeT++ for simulation. Hence, design and analyze an energy efficient context aware resource allocation for real-time tracking of the products in DSNs. The objective of the proposed work is to improve the performance of network in terms of energy consumption, time required for energy emergency level, throughput, and resource allocation with different contexts.

Keywords - *Distributed Sensor Networks (DSNs), Context Aware, Time Context, Seasonal Context, Hybrid Context, Cluster Head (CH), NKB, and OMNET++*

1. Introduction

Advances in Micro Electro Mechanical System (MEMS) technologies have created low cost, low power, multifunctional tiny sensor devices. These devices make up several numbers of ad-hoc tiny sensor nodes spread across a geographical area. These sensor nodes collaborate themselves to establish a sensing network. DSNs have been one of the choices for building smart environments. Smart environments can be designed for building, utilities, military, shopping mall, industrial, home, shipboard, and transportation systems automation. Sensory data generated from multiple sensors in the network is used for creating smarter environment [1].

The main objective of DSN is to make the decisions or gain the knowledge based on the information fused from distributed sensor nodes data. At the lowest level, individual sensor node collects data from different sensing modalities. An initial data processing can be carried out at the local node to generate local event detection result. These intermediate results can be integrated or fused at an upper processing center to derive knowledge and help of making decisions [2].

The context environment leads to DSN devices or nodes in contexts, i.e., the ability of device or program to sense, react or adapt to its environment to use. The optimal heuristic techniques are used to solve complex real time problems such as context aware devices, context discovery, sensing, extraction and manipulation, which have a high degree of mechanism for providing flexible services as well as quality of services. This information can be utilized to create smarter environment to achieve the challenges like detecting the relevant quantities, monitoring and collecting the data, assessing and evaluating the information, formulating meaningful user information, resource allocation, and performing decision making [3].

Context awareness is one of the heuristic methods to improve resource utilization in DSNs. The different types of contexts for retail industry based on human perspective are considered in this work. At a basic level of design, sensors are deployed in each rack, which provides the real time information about available products in each rack. This information can be used by warehouse manager and store manager for day to day activity in super/hyper market. Research and Development (R&D) team can also use this information to understand consumer behavior. The context information derived from sensor node is used for allocation of sensor node or resources.

OMNeT++ is a public-source, discrete event simulation, component-based, modular and openarchitecture simulation environment with strong GUI support and an embeddable simulation kernel. Its primary application area is the simulation of communication networks. Because of its generic and flexible architecture it has been successfully used in other areas like the simulation of IT systems, queuing networks, hardware architectures, and business processes. OMNeT++ is rapidly becoming a popular simulation platform in the scientific community as well as in industrial settings. Several open source simulation models have been published, in the field of Internet simulations (IP, IPv6, MPLS, etc), mobility and ad-hoc simulations and other areas. However, such a growing community faces also growing challenges and problems: Integration of different simulation tools, porting of simulation models between different platforms, testing and comparison of applications [4].

The rest of the paper is organized as follows: Section 2 presents an overview of related work. The proposed work is discussed in Section 3. Simulation and results analysis are presented in section 4, and finally conclude the proposed work in section 5.

2. Related Work

Some of the related works are as follows: The work given in [5] presents a context aware approach to conserve the energy in WSN. This approach improves the efficiency of routing and network lifetime. The context aware of network is used to achieve better performance of the network. Hence this approach encompasses several key strengths such as modularity and generosity in WSN.

The work given in [6] discusses many applications of context aware system, especially for old age peoples. Periodically, the context aware system reminds the information of medicines to old age peoples i.e. when it is time to take their medication, and a medication monitor situated in a caregivers home that displays awareness information for elder users medication compliance.

The work given in [7] discusses the context aware DSN for dementia patients. Incontinence in patients with dementia (PWD) due to a decline in their physical and mental abilities. Those PWD may lie in soiled diaper for prolonged periods if timely diaper change is not in place. Current manual care practices may not be able to immediately detect soiled diaper, although costly and labor intensive scheduled checks are performed. Delays in diaper change can cause serious social and medical issues. It uses different sensors like wet sensor, pressure sensor, and accelerometer to design DSNs which help in managing the PWD. Inputs from these sensors are also used to conserve battery power, either by reducing sampling rate of sensor or by switching off the sensor itself.

The work given in [8] presents combinatorial auctions for resource allocation in a DSN. It discusses a solution to the problems posed by sensor resource allocation in an adaptive, distributed radar array. They have formulated a variant of the classic resource allocation problem that takes advantage of the locality of resources and tasks, which involves translating tasks and possible resource configurations into bids that can be solved by a modified combinatorial auction.

The work given in [9] describes the resource allocation for a DSN. It describes a project undertaken for the office of Force Transformation (OFT) to investigate alternative resource allocation strategies for America’s armed forces. The simulation of this work is carried out using agent based modeling to explore the emergent properties of a DSN. It focuses on the task of using distributed sensors with varying characteristics and capabilities that are trying to detect and track the movement of enemy units in an urban environment. The goal of the project is to identify the impact of different resource allocation strategies on the performance of the DSN.

The work given in [10] presents a resource allocation and congestion control in DSN. The bandwidth allocation for requesting sensor nodes in DSN is described. The establishment of the overall objectives of a DSN is a dynamic task so that it may sufficiently well track its environment. Resource allocation to each input data flow and congestion control at each decision node of such a network must be performed in an integrated framework.

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In this paper, the effectiveness of a 'per-flow' virtual queuing framework that decouples the input data flows to each decision node is demonstrated. Under this framework, the buffer set point level of a decision node is established via the control of set point levels of individual virtual buffers assigned to each source node. Some of the works given in [11][12][13][14] [15] [16].

The real time product tracking in retail industry with context aware DSNs for resource allocation is not found in any work. The three types of contexts have been proposed namely time context, seasonal context, and hybrid context. These contexts are used in product tracking and resource allocation in the DSN environment. DSNs always work under constrained resources. The resources can be any type like computational power, network bandwidth, battery power, memory or sensor node itself. Main objective of resource allocation is to increase the overall network life time of DSNs. Data caching, data aggression, context summarizing, and mobile agent based data collection are few important techniques to improve network life time of DSNs by conserving resources.

3. Proposed Work

DSNs are mainly used for monitoring, tracking and remote controlling the system. The novel context aware resource allocation in retail chain management is proposed by considering the case study of Indian retail industry. The weight sensors are considered in the proposed work, which are used to compute the data by using three types of contexts (seasonal context, time context, and hybrid context). Each sensor node forwards the data in a regular interval over the network, depending on the context and available information, each sensor node derives an emergency value.

The contributions of the proposed work are as follows. (1) Collection of the data and interpretation of the context, which are based on the collected data. (2) Selection of special intermediate sensor nodes (weight sensors) for detecting resources (different locations in the retail industry management) for connecting the event and sink node. (3) Computation of resource allocation based on the different contexts (i.e., seasonal context, time context, and hybrid context) by using special weight sensor nodes. (4) Based on the context, sensor node derive emergency value to be employed by weight of neighbor sensor nodes. (5) Monitoring of retail industry management system using context aware of resource allocation. (6) Different context manager nodes are defined for data gathering and resource allocation, and interpretation of the context. (7) Improving the performance parameters such as energy consumption, throughput, packet delivery ratio, and resource allocation and (8) Simulation of the proposed scheme for improvement of the performance parameters.

This section presents network environment, proposed contexts, retail chain management, proposed modules for the retail chain management, and emergency context interpretation model.

A. Network Environment

In the proposed system, sensor nodes are deployed to obtain the real time information namely, availability of products in the retail shop. DSNs may be designed to have one or more heterogeneous sensors. The fig. 1 presents the network environment, in which distributed sensor nodes are deployed manually. Each rack contains sensor nodes, which keep track of available information (compute the number of items) in time context, seasonal context information and hybrid context information. The group of sensor nodes forms clusters, which are placed in each rack.

In each cluster, selection of cluster head (CH) randomly. Sensed data is communicated to sink node in hierarchy. The information or data is sent to the CH in the regular interval. The CH collects the data from its member nodes for data aggregation. For data aggregation, CH uses duplicate suppression technique for data aggregation. CH forwards the aggregated data to the sink node through other neighboring CHs in DSN.

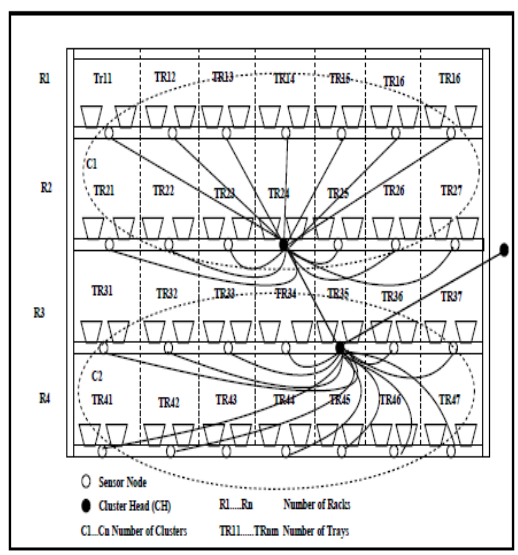

Fig. 1. Network Environment.

IJCSN International Journal of Computer Science and Network, Volume 6, Issue 2, April 2017
ISSN (Online) : 2277-5420
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B. Proposed Contexts

The contextual information reflects real time situations and events in DSN environment. CAC systems utilize this information to adapt services or interfaces provided to their users. In the proposed system, contextual information is derived for the retail industry with three types of context, namely time context, seasonal context, and hybrid context. Sensor nodes are deployed to sense each tray in real time.

The sensed data is forwarded to its CHs for data aggregation, which in turn forwarded to sink node. Since sensor nodes work under constrained resources sampling, computation and data transmission can be reduced greatly by applying contextual information of the retail industry. In the proposed work, three types of contexts derived for efficient resource allocation in retail chain management, which are defined as follows:

- **Time Context:** Products related Fast Moving Consumer Goods (FMCG) decline quickly compare to other products in retail shops. Periodically, sensor nodes situated in rack monitors the availability of the products in the rack. In this regard, sensor nodes are configured with time context mode. In time context mode sampling rate, data aggregation is optimized based on the rate of depletion of respective resources. Further sensor nodes transit to schedule sleep mode to conserve energy. Resource monitoring without deriving contextual information decreases the network lifetime.
- **Seasonal Context:** The rate of reduction for certain products may be based on a season like summer, winter or rainy season. In the proposed system, sensor nodes tracking the product type and are not necessary to sense the availability of product periodically. Nodes tracking the products are configured with seasonal context. Nodes configured with a seasonal context are transit to sleep mode for a longer time compared to time context. Energy consumption is also comparatively lesser than sensor with time context.
- **Hybrid Context:** Certain products neither belongs to time nor seasonal contextual category such products are configured with hybrid context. These sensor nodes have less sampling frequency compare to time context, but have a higher sampling rate than seasonal context. For these sensor nodes schedule sleep time is much higher than time context sensor. Reducing sampling rate and unnecessary computation enhances the battery life of the sensor node.

C. Retail Chain Management

The fig. 2 shows the proposed model for retail chain management. The different types of contexts are considered for efficient resource allocation in the DSN. These types of context provides the following advantages namely, optimized node deployment, increase in network lifetime, reduced network bandwidth, data aggregation or fusion, and reduced sampling rate of the sensor nodes. The proposed model consists of four different types of modules namely context manager module (CMM), policy management module (PMM), emergency context module (ECM), and computational context module (CCM).

The sensor nodes in each rack, forwards the context information to the sink node through its CH in DSN. Sensor information is updated in the node knowledge base (NKB). Context broker module reads the information from the NKB and supplies it to the CCM. CCM defines the ECM by considering context cache, summarization, pattern matching, and data aggregation. This type of context is handled by ECM in the DSN. This data is used by PMM to reprogram targeted node in the DSN environment. At present working model of the retail industry, Floor Manager (FM) has to do regular routine check up for availability of products in each rack. The proposed system is used to reduce the burden of Store Manager (SM) by deriving meaningful data from context aware system and also allocate the efficient resources depending on the context.

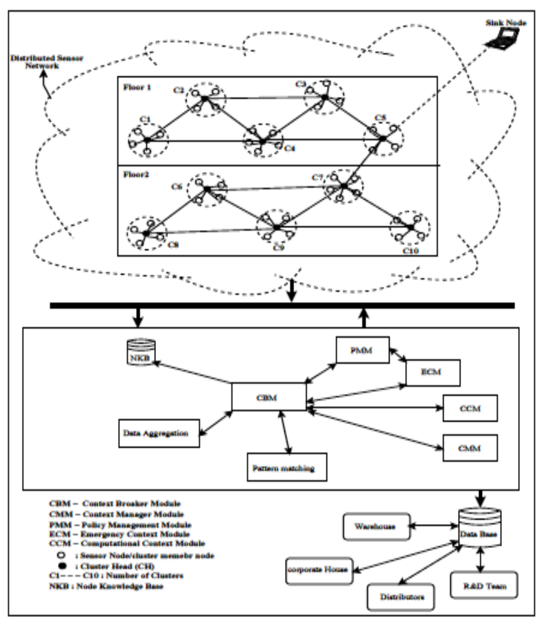

Fig. 2. Detail View of Proposed DSNs System Model for Retail Chain Management.

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D. Proposed Modules for the Retail Chain Management

Some of the modules that are used in this work are described as follows:

- **Context Manager Module (CMM):** CMM is responsible for allocating and releasing resource based on analysis done in human, system, and environment perspective. CMM provides the interface for defining, altering and deleting the contexts. It also provides interfaces to define attributes and its value for each context.
- **Policy Management Module (PMM):** PMM provides the interfaces to define strategies for entire context aware system based on organization or business requirement. Data derived from the ECM is used to reprogram the targeted node. A node can be reprogrammed according to the expected behavior of the system.
- **Emergency Context Module (ECM):** ECM derives different level of decisive action to be taken on the system. The emergency level is derived based on allocated resources, the rate of depletion of resources, system requirement and defined business policy that necessary action can be taken.
- **Computational Context Module (CCM):** CCM derives different contexts based on system resources. Since sensor nodes are deployed in remote territory with limited computational resources, computational resources are important. With this concern CMM derives context based on system resources.
- **Context Broker Module (CBM):** It reads the data from the NKB. CBM at sink node reads the data from NKB and use the context cache, summarization, pattern matching, data aggression, computation context Module (CCM) to derive emergency context, which is used by the ECM. This data is used by PMM to reprogram targeted node. Nodes are reprogrammed according to the context information.
- **Node Knowledge Base (NKB):** This knowledge base is read and updated by the sensor nodes or CHs. NKB comprises of node$_{id}$, active mode/sleep mode, sensing time, product - id, floor - id, emergency - level (E - level), previously sensed data, set of critical data, bandwidth information, number of cluster member node, the number of CHs, number of clusters, sink node information, and location of the node. The sensor node senses the data and updates the NKB. The detail view of NKB is shown in fig. 3.

The proposed system has the following advantages compared to existing model namely (1) Store manager (SM) is less dependent on Floor Manager (FM) for any kind of updates. (2) Product replacement within outlet for any floor can be done efficiently. (3) No need for routine checks up for each floor or rack. (4) Labor cost can be reduced drastically but requires little maintenance. (5) Warehouse managers can view the product availability at any time in each outlet. Sold products can be replaced to each outlet based on the emergency. This process takes at least one day in the present system. (6) The corporate head office can keep track of each and every outlet shop. (7) Product distributor is also getting enough time to prepare for supply and (8) The Research and Development (R&D) team can analyze the data obtained by this network for understanding consumer behavior. The proposed algorithm is as shown in algorithm 11.

E. Emergency Context Interpretation Model

Let $S_1, S_2, S_3, ...S_N$ be the sensor nodes deployed in each rack of retail chain management, and 'ρ' is the resource allocation factor, 'δ' is the emergency level factor at CHs, 'D_1' is the aggregated data, aggregated the data for other CHs is given by equation (1).

Node ID	P_ID	CH_ID	Status	Rack_ID	Floor_ID	E_level	Context	R_Status	Clusters	Requesting Nodes	Sampling Rate
2 4 6 3	P1 P2 P3 P4	CH3	ACTIVE SLEEP	R1 R2	F2	Medium	Time Context	76%	C2	2	200msecs (Time Context)
1 8 7 10 13	P5 P6 P7 P8 P9	CH2	ACTIVE SLEEP	R4 R6	F1	Medium	Seasonal Context	82%	C1	3	600msecs (Seasonal Context)
											1800msecs (Hybrid Context)

P_ID : Product ID
CH_ID : Cluster Head ID
E_level : Emergency Level
R_Status : Resource Allocation Status

Fig. 3. Detail View of NKB.

$$D_1 = \text{Data}(\text{CH}_i)$$

$$\delta = D_1 + (\sum_{r=1}^{n} \rho_C H_i) \quad (1)$$

Then,

$$\delta = \begin{cases} \leq 50\% & \text{Low Emergency Level} \\ \leq 70\% & \text{Medium Emergency Level} \\ \geq 70\% & \text{High Emergency Level} \end{cases}$$

The fig. 4 shows the network path representation for aggregated data from CHs to sink node in DSN. It is assumed that most of the sensor nodes carry the same data to CHs. CHs aggregates the data for redundant data elimination from its cluster member nodes along with data from other CHs. Finally, aggregated data is forwarded to the sink node through CHs. Emergency level context is defined based on the aggregated data by the sink node. If emergency level is high, sink node gives highest priority to requesting CH, next higher priority is given to next CHs and this continues on the path for each CH until the data is communicated to sink node.

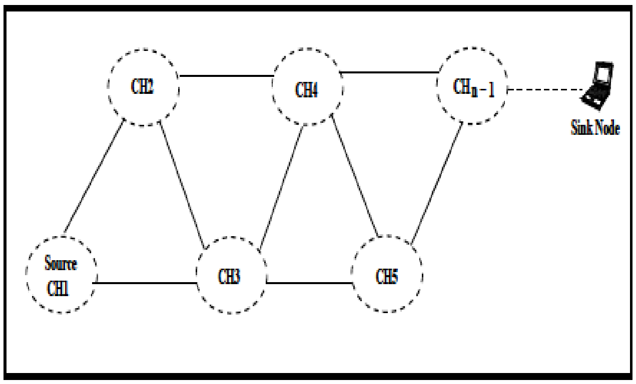

Fig. 4. Network Path for Aggregated Data.

CH forwards the aggregated data to sink node through other CH based on its given itinerary or chosen itinerary. The total energy consumption, T_E is given by equation (2).

$$T_E = E_S + (E_T \times N_h) \quad (2)$$

Where,

E_S = Energy required for sensing of data, E_T = Energy required for transmission of data, and N_h = number of hops required to transmit the aggregated data from CHs to sink node.

The proposed algorithm is simulated in OMNET++ simulation tool. The procedure of proposed algorithm is as follows: at startup(), initialization of each node based on type of resource, that has to be tracked. Nodes are configured with rack_ID, product_ID, context_Type, and emergency_Level. For sensor nodes with timer context are initialized with startTxTime (200ms) timer value. seasonal and hybrid nodes timer callback are initialized with multiples of startTxTime i.e. startTxTime × 3 (600ms), startTxTime × 9 (1800ms) respectively. After timeout, emergency value is checked for medium or high. If the emergency level is either medium or high, packet is sent to SINK node.

If the Node is CH, emergency level is aggregated and forwarded to sink node. In case of sink node, emergency level is checked for high. In case of high emergency level, information is sent to store manager to restore the depletion products. The specific() collect information needed for statistical analysis of battery level, throughput, energy spent while transmitting or receiving packet.

4. Simulations

The simulation of the proposed scheme is carried out by using Castalia simulator (OMNeT++). The proposed model has been simulated in various DSN scenarios. Simulations are carried out extensively with random number for 100 iterations. This section presents the simulation model, simulation procedure, performance parameters and results and discussions.

A. Simulation Model

The simulation model consists of 'N' number of sensor nodes deployed manually in DSN environment. Simulation is done for 'N' (N = 100) sensor nodes used to measure the performance parameters such as number of packets transmitted, energy utilization, time required for emergency level, throughput, and resource allocation with configuration of time context, seasonal context, and hybrid context in DSN.

B. Simulation Procedure

To illustrate some of the results of simulation, the following variables are considered in the proposed scheme namely length (l) = 100 meters and breadth (b) = 100 meters, Number of Nodes (N) = 100 nodes, number of sink node (N_S) = 1, simulation time (S_T) = 7000msecs, energy required for transmitting single packet [Tx mode power] = 46.2mwatt, energy required for receiving and processing single packet [Rx mode power]= 62mwatt, initial energy/power of sensor node [power to two AA batteries] (I_P) = 18720Joules, Baseline node power [even if node is not transmitting or receiving]= 6mwatt, data rate (D_R)= 250kbps, modulation type (M_T)= PSK, and bandwidth (b)= 20MHz.

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Table I: Delay Transmission Matrix (mSecs)

	Rx	Tx	Sleep
Rx	–	0.01	0.194
Tx	0.01	–	0.194
Sleep	0.05	0.05	–

Table II. Power Transmission Matrix (mV)

	Rx	Tx	Sleep
Rx	–	62	62
Tx	62	–	62
Sleep	1.4	1.4	–

Tables I and II are used in the simulation of the proposed work. Simulation procedure involves following steps are.

Begin

- Deploy the number of sensor nodes manually in DSN environment;
- Construct the numbers of clusters in the environment;
- Selection of CH within the clusters randomly;
- Configuration of each sensor node according to context types for efficient resource allocation;
- Apply the proposed scheme;
- Compute the performance parameters;

End

C. Performance Parameters

The following performance parameters are used to measure the performance of the proposed scheme.

1) **Energy Consumption:** As the time increases, energy consumption or utilization of energy of sensor node also increases in different contexts. It is measured in terms of 'mJoules'.
2) Time Required for Emergency Level: As the number
1) of node increases, time required for emergency level also increases in different contexts. It measures the in terms of 'mseconds'.
2) Throughput: It is the ratio of number of packets sent to the number of packets received successfully.
3) Resource Allocation: As the number of active nodes increase in each cluster, resource allocation also increases in DSN environment. It measures the percentage of resources allocated successfully to all the nodes in different contexts. It is measured in terms of percentage.

D. Results and Discussions

The fig. 5 shows the energy consumption with time (msecs) in different contexts. Fast Moving Consumer Goods (FMCG) require frequent sampling of data for sensor nodes, which sample FMCG is configured for time context mode. Other nodes are configured to either hybrid or seasonal context. The sensor node with time context looses energy significantly as compared to seasonal and hybrid contexts. In time context sensor nodes, energy consumption is almost linear and it is much higher as compared to other contexts. The energy consumed by hybrid context sensors is less than a 25% that of time context sensor node.

Nodes configured with seasonal context dissipate less energy as compared to time context and hybrid context sensor node. Energy consumed by seasonal context is almost 1/10th of the timer context node. Energy saving seasonal context node is due to analysis of domain or human specific prospective. This in turn reduces unnecessary sampling, processing of packet, and transmission of packet across the network.

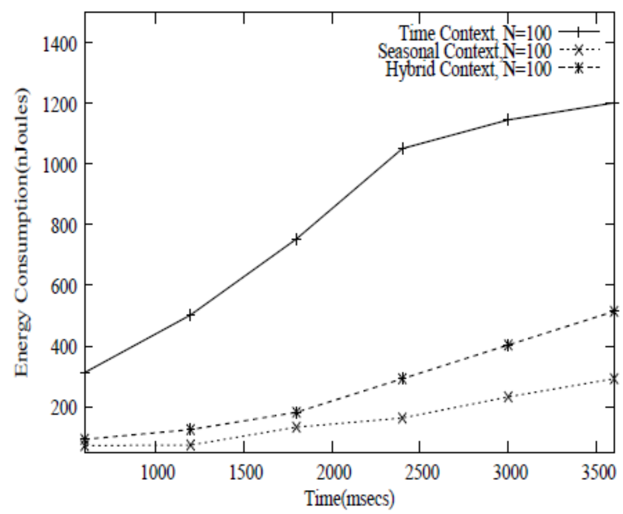

Fig. 5. Energy Consumption Vs.Time.

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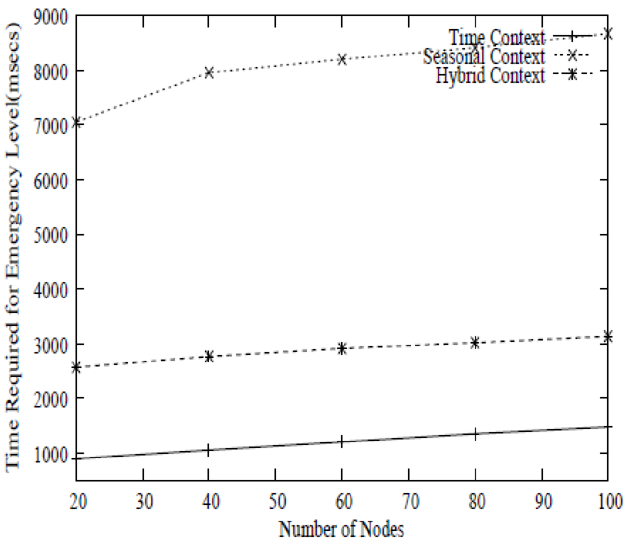

Fig. 6. Time Required for Emergency Level Vs. Number of Nodes.

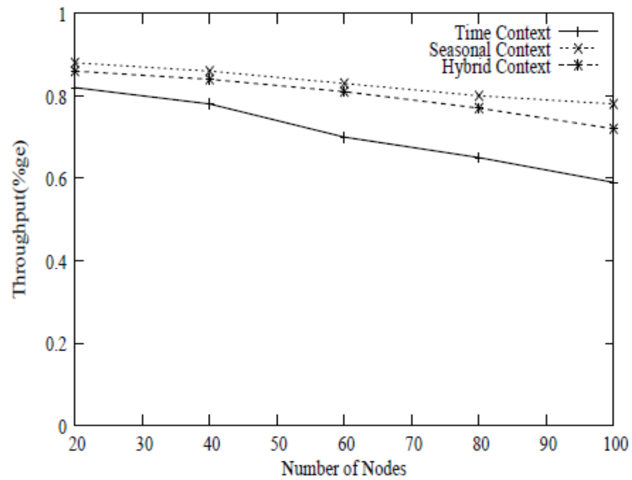

Fig. 7. Throughput Vs. Number of Nodes.

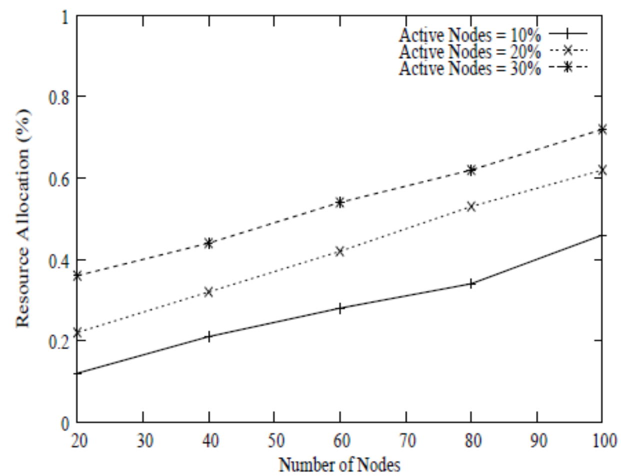

Fig. 8. Resource Allocation Vs. Number of Nodes.

The fig. 6 shows the time required for emergency level in each context. As the number of nodes increase, emergency level also increases. As compared with seasonal and hybrid context, less time is required for time context in DSN. Sensor nodes configured with a seasonal context is transit to sleep mode for a longer time compared to time context. Generally, FMCG products are replaced on daily basis. In the proposed work, sensor nodes are configured to time context to monitor FMCG goods. The results shows nodes monitoring FMCG with timer context reaches emergency level quickly compared to hybrid and seasonal context node.

The fig. 7 shows the throughput in different context. Throughput depends on number of packets sent and received successfully to the sink node. As the number of nodes increase, throughput gradually decreases in all the contexts because of congestion in the network. In seasonal context, number of packet sent to sink node is less compared to time and hybrid contexts. This generates less traffic across the network, which results in lesser collision compared to hybrid and time context. This results in higher throughput.

The fig. 8 shows the percentage of resource allocation in different contexts. As the number of active nodes increase in contexts, there is increase in resource allocation also for requesting active nodes in DSN. At any point of time, only cluster node and transmitting nodes are active in any cluster group. The remaining nodes transits to sleep state. Since nodes shares global clock, scheduled activation of nodes considerably increases the percentage of resource allocation.

5. Conclusion

Context aware systems are designed using human perspective, domain specific information. The drawbacks of Indian Retail Industry are analyzed in the proposed scheme. In the proposed work, sensor nodes are deployed in each rack that provides the real time information of products available in each rack. This information can be used by warehouse manager, store manager for day to day activity in super market or hyper market. R&D team can also use this information to understand consumer behavior.

To save the energy further, nodes are programmed to sleep state immediately after sending the information to cluster node. A simulation result shows the advantages of embedding the context awareness in system for resource allocation. Bandwidth utilization, energy consumption is greatly reduced in each context. The proposed work is simulated by using Castalia simulation tool which is based on OMNeT++. Finally, performance parameters are evaluated for the proposed scheme.

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