D-CAS: Distributed and Adaptive Channel Assignment Scheme for Clustered Wireless Sensor Networks

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***Abstract*-This paper proposes a distributed and adaptive channel assignment (D-CAS) scheme for wireless sensor networks. D-CAS performs statistical analysis of load pattern of the individual cluster and adjusts channel assignment dynamically as per requirement generated by the current cluster' traffic load. It follows a static schedule during infrastructure establishment based on initial traffic conditions and previous history. Later, it utilizes dynamic schedule for channel adjustments. Over a period of time, learning efficiency of the load prediction increases due to availability of more traffic patterns, which in turn, reduces transmission wait and increases the system throughput and network life significantly. It provides seamless data transmission even in peak hours and is highly immune to the random traffic change. This algorithm optimizes the channel utilization by best-of-four strategies and meets the real time requirement of sensor network applications. This algorithm is distributed at clusters level and central at node level i.e. it collectively possesses the advantages of all four: static, dynamic, central, and distributed channel assignment approaches. This paper ends with planned future work which includes simulation, performance analysis, and traffic prediction accuracy.**

Index Terms – Sensor Network, Channel Assignment, DCA, SCA, Hybrid, Distributed.

INTRODUCTION

Advances in MEMS/NEMS have enabled the wireless sensor technology to automate many day to day applications. These days high bandwidth data transmission also has been made possible over the wireless links like live video transmission from an inhospitable region. Such applications need high quality of service (QoS), for example, guaranteed services, multimedia services, differentiated services, or delay sensitive services. Seamless data transmission is one of the requirements for such high reliability sensor network applications.

Sensor Network life [1] is another big challenge especially when it is deployed in inaccessible region as they are limited power driven networks. The power is dissipated from sensor node depending on how long any node is transmitting, receiving, or turned-on and waiting for data transmission having data in hand. The drainage in the sensor node battery may lead to a hole in the network, if the network is not too dense. In case of inaccessible region, it is difficult to replace the battery or node itself. An alternative to this problem can be to design such efficient transmission/reception schedules, or delay/power aware algorithms, etc. that may lead to minimization of power consumption.

Communication is another major factor that is also responsible for energy consumption in wireless sensor networks. The centralized algorithms [2] require more communication power than distributed algorithms. Specifically, when we talk about channel assignment issues centralized algorithms consume more energy for channel settlements in the whole network. The distributed algorithms require less communication for channels settlements but sometimes starve because of availability of less information.

Static channel assignment (SCA) [3] schemes are fixed allocation schemes. In this strategy, channels are allocated to each cell based on initial network planning. Channel re-shuffling is not permitted in the network later. SCAs are very effective for the network where traffic is almost stagnant. But such schemes face other issues like channel availability, transmission delays, weak QoS, etc. On the other hand, dynamic channel assignment (DCA) schemes [4] overcome this problem but lead to excessive communication overhead.

The algorithm proposed in this work has various advantages with little trade-off because of relatively more memory and processing power requirements at cluster level. These resource requirements do not have major impacts on network cost, when it is compared to over all increased network life and real time application requirements. In other words, algorithm has drastic improvement over network life as well as data transmission rate/delay. This algorithm is better suited for applications with variable traffic e.g. structure (bridge/building) monitoring, forest monitoring for animals, activity monitoring, etc. The contribution of this paper is summarized as follows,

- This algorithm decides to use the best of four strategies, namely, static, dynamic, centralized, and distributed concepts i.e. it is a hybrid approach.
- It is delay sensitive i.e. real time data reporting to base station or data center. Hence this algorithm is highly useful for real time applications.
- Its distributed nature leads to a huge cost cutting in communication.
- Proposed algorithm runs in the order of $O(Nc*S_{avg})$ i.e. quick responsive, where N_c – Number of clusters in wireless sensor network, and S_{avg} – average cluster size.
- Power saver i.e. increased network life which is a big requirement in sensor network applications because sensor nodes are powered by batteries.

The central or global channel assignment schemes [2,5,6] face problem of heavy communication overhead, especially during peak hours. The static channel assignment schemes [3] starve when variable traffic conditions occur. The dynamic channel assignment scheme [4] is very well suited for variable traffic load but on the other hand, it incurs unnecessary communication overhead for almost steady traffic conditions. WSNs are powered by battery and power saving is big issue in such networks. D-CAS is hybrid algorithm that incorporates the best of all categories and has significant gain in terms of power consumption, transmission delay, QoS, etc.

Pink circles in figure1 represent the cluster head, blue circles are sensor nodes, and big green circles represent the cluster.

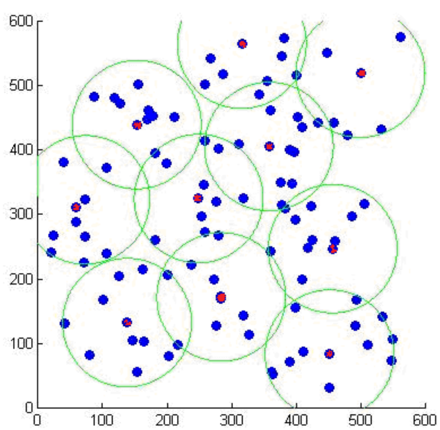

FIGURE 1
CLUSTERED WIRELESS SENSOR NETWORK

Following is the initial traffic pattern shown graphically and figure 3 shows a portion of figure 2 numerically represented traffic indices in each cluster.

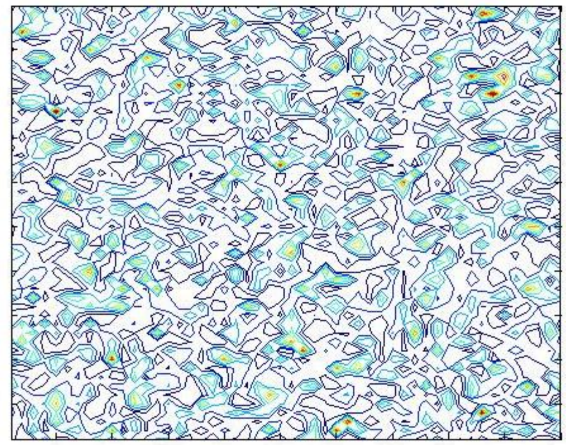

FIGURE 2
INITIAL TRAFFIC DENSITY IN CERTAIN ACTIVITY REGION

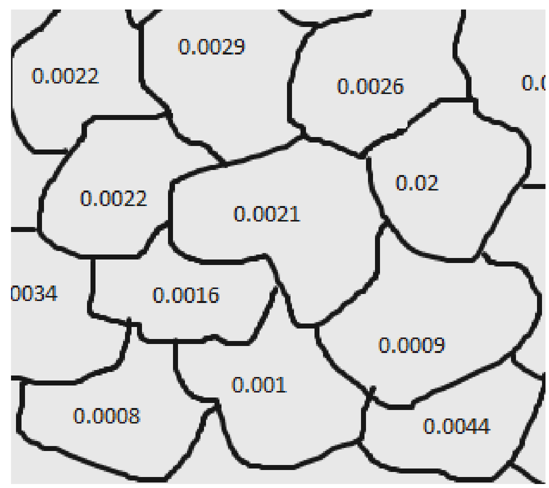

FIGURE 3
INITIAL TRAFFIC PATTERN (A PORTION OF FIGURE 2) BASED ON POISSON DISTRIBUTION AND PREVIOUS HISTORY, NUMBER SHOWN IN CLUSTER IS TRAFFIC INDEX I.E. RATIO OF TRAFFIC AT CLUSTER OVER AGGREGATE TRAFFIC IN NETWORK.

The next Section gives theoretical details used, in brief. Section 3 presents an overview of the proposed Distributed adaptive channel assignment strategy. Subsequently, section 4 describes simulation model. Finally the paper ends with conclusion and future work.

THEORY

In general, traffic arrival behavior follows a Gaussian variation [7] over a period of time. At inception and demise, system is in almost no load condition and load is highest during peak hours. Some sensor network applications, for example, activity monitoring can be modeled using the same assumption.

Number of estimated channels at time *t* in cluster *i* are given by

$$Ch_{estimated}(t)_i = Ch_{total} T_i \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{1}{2}(\frac{\alpha_t - \alpha_m}{\sigma})^2} \qquad (1)$$

T_i = Weighted Traffic index based on previous traffic history, and $0 < T_i < 1$.
σ = Variance
α_t =Traffic load at time *t*
Ch_{total} = Total Number of Channels
α_m =Mean traffic load

Where,

$$\alpha_m = \sum_{i=1}^{N_c} \frac{\alpha_i}{N_c} \qquad (2)$$

N_c = Number of clusters
α_i =Number of channels at cluster *i*
Average cluster size (S_{avg}) can be calculated as follows,

$$S_{avg} = \sum_{i=1}^{N_c} \frac{cS_i}{N_c} \qquad (3)$$

cS_i = Size of i^{th} cluster

Current channel adjustments for cluster,

$$f_{mn} = Ch_{estimated}(t)_i - Ch_{actual}(t) \qquad (4)$$

We can investigate the new channel requirements at time *t* in cluster *i* as follows:

$$c_i = \begin{cases} f_{mn} > 0, & \textit{Demand of channels } \lceil f_{mn} \rceil \\ f_{mn} = 0, & \textit{No demand/surplus} \\ f_{mn} > 0, & \textit{Surplus of channels } \lceil |f_{mn}| \rceil \end{cases} \qquad (5)$$

Spectral efficiency (η_s) has been calculated using Walke's [8] formulae.

$$\eta_s = \frac{\alpha_i}{\lambda_s A_c} \qquad (6)$$

Where A_c is cluster area and λ_s is system bandwidth.

ALGORITHMIC DETAIL

This algorithm has centralized behavior within the cluster and nodes only need to communicate very short distance, hardly 1-2 hops depending upon the clustering criteria. They directly report the semi processed data to nearest base station. The Cluster Head continuously monitors the current channel requirement based on current and/or future traffic conditions and makes the comparative study of the estimated channel requirement and available channels at current cluster. It then finds out the surplus/requirement of channels, if any. If there are surplus channels at current cluster, this algorithm forces it to release the channels, and makes them available for others to use. In this way, system adapts with the random traffic conditions.

As explained above, pre-allocations are made during infrastructure establishment based on initial traffic indices as shown in figure 2. D-CAS runs periodically at every cluster and makes the judgment about new channel allocation as per local traffic conditions. In case of scarcity, cluster head request for more channels from neighbors. D-CAS also evaluates the channel requirement in certain intervals, and releases (soft) surplus channels i.e. marks them unallocated. These unallocated channels are used by neighboring clusters in need. All the channels information is maintained by the cluster heads in the form a three dimensional matrix. The following matrix has been introduced to hold the channel information; network is assumed to be a $m \times n$ matrix.

$$C_{mn} = \begin{bmatrix} [c_{11}]_{i\times j} & [c_{12}]_{i\times j} & \cdots & [c_{1n}]_{i\times j} \\ [c_{21}]_{i\times j} & [c_{22}]_{i\times j} & \cdots & [c_{2n}]_{i\times j} \\ \vdots & \vdots & \vdots & \vdots \\ [c_{m1}]_{i\times j} & [c_{m2}]_{i\times j} & \cdots & [c_{mn}]_{i\times j} \end{bmatrix} \qquad (7)$$

Where

$$c_{ij} = \begin{cases} 1, & \text{Channel } i \text{ is allocated to node } j, \\ 0, & \text{Otherwise} \end{cases} \qquad (8)$$

C_{mn} is stored in base station in order to track traffic pattern at any time. This matrix is getting updated when any cluster registers its presence in response to periodic beacons from base station. This matrix tells the channel information about complete network.

c_{ij} resides at every cluster and maintains current channel information and gets updated as per channel allocations.

I. Traffic Aware Algorithm

```
//This algorithm is executed at every cluster.
```

```
//t_tperiod: Time period for load monitoring

Execute every t_period {

      Ch_actual = Count one's in c_mn for all i, and j
      using (8)
      Compute Estimated total channels using (1)
      f_mn = Find the adjustment for current cluster
      using (5)
      if (f_mn >0){
            Release (soft) the ⌈f_mn⌉ channels
       else
            if (f_mn !=0){
                  Borrow ⌈|f_mn|⌉ channels from
                  neighbors
                  Disassociate from parent cluster's
                  pool (Hard Release)
                  Add borrowed channels to local
                  channel pool
            }
            else {
                  No adjustment required
            }
      }
}
```

II. Definitions

- **Soft Release:** Soft release is a process by which channel is made unallocated but stays associated with same channel pool.
- **Hard Release:** In hard release channels are completely disassociated from the parent channel pool and get allocated to another cluster's channel pool.
- **Neighbor:** Node *A* is said to be neighbor of Node *B* and vice-versa, if $edist(A, B) \leq C_d$, where C_d is communication distance and $edist(A, B)$ is Euclidean distance between both the nodes.

SIMULATION

The simulation model will be implemented using an activity area shown in fig.1. Traffic pattern will be considered as non-uniform activity region. Traffic pattern will be programmed in a way that creates non-uniformity in activity to test the adaptivity. We are planning to analyze the adaptivity level by varying the randomness of the activity and traffic load, transmission delay, spectral efficiency, quality of service, etc. We are also planning to evaluate performance with respect to individual behaviors like central, distributed, static, and dynamic.

CONCLUSION

In this paper, we are expecting to achieve significant improvements in transmission delay, power saving, utilization of bandwidth, Quality of Service, etc. Our algorithm is suitable for real time applications where response is really critical and especially for applications with variable traffic load. For example, activity monitoring, infiltration monitoring, etc.

Our future work will be on simulation, performance analysis and also accuracy of the traffic prediction that will give us more accurate adaptation information to act on. Also there are plans to test on real hardware and observe the differences between real implementation and simulated results.

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