Is It Worth Taking A Planned Approach To Design Ad Hoc Infrastructure For Post Disaster Communication?

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ABSTRACT

After any natural disaster the availability of existing conventional communication infrastructure almost gets ruled out. After the devastation, to restore the communication system in ad hoc basis; ensuring almost 100% packet delivery within acceptable latency with optimal utilization of resources are prime design motives. Our work proposes a four tier planned hybrid architecture, which conforms the aforesaid motives yielding a desired performance in terms of delivery probability within least latency, for a given disaster hit area map with a suitable heuristic algorithm. Our study also reveals that there exists no deterministic polynomial time solution that can implement the desired design motives as well as the feasibility of our planned methodology. Compared to any brute force strategy, as per the simulation results, our approach shows 42% higher delivery probability and 49% lower latency.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless communication

General Terms

Design

Keywords

Post Disaster Management, Ad Hoc Hybrid Network, Latency, Delivery Probability

1. INTRODUCTION

Large scale natural disasters can severely impair conventional communication infrastructure(CDMA / GSM / PSTN / WLL), largely affecting human life. Many of the disaster prone areas like the Sundarban (longest mangrove forest; disaster-prone and highly under-developed rural area), Himalayan terrain, etc. do not have quality infrastructure even during normal time. In such areas, during disaster, mobile phones working in Delay Tolerant Network (DTN) mode can be only option to exchange information due to intermittent connectivity, which however suffers from unpredictable latency (packet delivery time) and poor packet delivery probability.

Here we raise fundamental questions: **Is it worth/feasible taking a planned approach to handle a disaster scenario with computational and deployment overhead and whether it would be acceptable in terms of performance? Specifically, is there any significant performance gain of developing optimal deployment plan compared to any brute force approach ?** Brute force approach implies the design of network infrastructure based on previous experiences and intuitions without any algorithm.

The novelty of our work is: introducing a properly planned four tier hybrid architecture with its feasibility study using data mules that promises to meet the goal. We also show that our architecture design, under latency constraint ensuring optimal utilization of resources, leads to two NP hard optimization problems: *(i) Graph clustering, (ii) Multi Depot vehicle Routing problem (MDVRP).* To the best of our knowledge, none of the previously designed architectures like WMIDAES[1], ENS[2], DakNet[3] provide a customized solution ensuring optimum utilization of resource and performance guarantee with latency awareness.

2. PROPOSED ARCHITECTURE

In our architecture as shown in figure 1; there is utilization of lower range & cheaper devices at bottom layer towards building the next higher ones with higher range & costlier devices when the scenario cannot be handled by the lower layer. It has a fixed Master Control Station(MCS) to control centralised rescue/relief operations within disaster Affected Area(AA) consisting of many Shelter Points(SPs). Rescue personnel within each SP carrying smart phones form DTNs [**Tier-1**] to exchange information & deliver packets periodically to the nearest DropBox(DB) [**Tier-2**] of each SP. For sparse DTNs and far DBs, we propose that, vehicles used by rescue/relief teams are equipped with Wi-Fi and VSAT (for emergency messages) & act as Data Mules (DMs) (mechanical back-hauls) [**Tier-3**] to carry informations to MCS, within desired L. Where nearly placed SPs become inacces-

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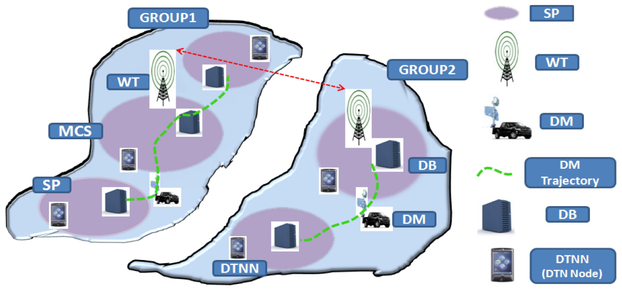

Figure 1: Four Tier hybrid Architecture using DTN Nodes, DropBoxes(DBs), DataMules(DMs) and WiFi Towers(WTs)

sible by DMs due to physical obstructions, wireless mesh can be a good choice. If AA has a large diameter; deploying a dedicated DM per SP is infeasible option to meet latency constraints. So, there should be sharing of one DM among several SPs. Hence, a grouping of SPs with efficient clustering algorithm is done and at each group center one (NLOS/near LOS) Wi-Fi tower (WTs) **[Tier-4]**, accumulating data from a non-overlapping set of DBs is placed.
In aforesaid architecture, two objectives need to be met: **Objective 1:** Finding the optimal number of WTs with their positions required to meet desired L; moreover, finding non-overlapping subsets of DBs to be assigned to corresponding WTs. **Objective 2:** Given a group of DBs assigned to a WT and finding the minimum number of DMs required to traverse those within L & finding the trajectory of each DM meeting both objectives are NP hard in nature. Next we discuss corresponding solutions.

3. PROBLEM FORMULATION AND PROPOSED HEURISTIC SOLUTIONS

The SP corresponds to the vertex set and the pathways among the SP corresponds to the edge set of that graph G(V,E) where V = $\{SP_i\}; 1 \le i \le m$ and E = $\{E_{ij} \mid E_{ij}$ are pathways between vertices SP_i & $SP_j\}$ $1 \le i \le m$ & $1 \le j \le m$. Each vertex SP_i has service time ST_i.The whole graph G(V,E) is divided into a set of groups where the set is GR. The vertex set of graph G will be divided into two sets. One is the set of group medoids GC and another one is the set of non-medoidal group members GM ; subject to the following,
$V = GC \cup GM$
$K = \mid GC \mid = \mid GR \mid$
$GR = \{gr_i\},\ GC = \{gc_i\}\ where\ 1 \le i \le K$
$GM = \{gm_j\}, 1 \le j \le m\ \&\ i \ne j$
Every gc_i corresponds to only one gr_i.
Our problem has two subproblems for which we have approached heuristic solutions.
Subproblem 1
Optimal group formation subjected to a minimization function of L; every element of set GM must be associated with any one element of set GC. We have formulated our above stated problem under the classical clustering algorithm of *Geodesic K medoid Clustering algorithm*[4] imposing an additional constraint of Time Bound i.e Allowable Time(AT) for desired output. The achieved L should be minimum and within AT.

Algorithm 1: Group_Optimization

Input: *SP, ST, Pathways among SP, MCS, AT.*
Output: *Number of groups(K), Number of WTs required, Number of associated SP with each WT and their positions.*
1. Initialize neighbouring SPs of MCS to form initial set of group medoids.
2. Initialize K by Number of adjacent SP of MCS including itself.
while *(groups are not stabilized)* **do**
  for *(all group medoids)* **do**
    assign all those possible non-medoid SPs as member of each group medoid satisfying the constraint of minimum latency within time bound.
  end
  for *(all non-medoid SP left out to be assigned)* **do**
    1: make it a group medoid.
    2: update group medoid set GC.
  end
  for *(all smallest group)* **do**
    if *(all its members including the medoid are assignable to other group)* **then**
      1: divide that group and absorb it to another group.
      2: update the group medoid set GC.
    end
  end
  for *(all groups)* **do**
    if *(better choice of group medoid exists)* **then**
      update group medoids set and non medoid set.
    end
  end
  K = |GC|.
end
3. Create a complete graph whose Vertex set: the set of medoids i.e GC & Edge set : all edges between all pair of vertices where Edge weight is Euclidean Distance between the vertices
4. Find Minimum Spanning Tree of above graph
5. Set up WT at each vertex of graph.
if *(Adjacent WTs are out of Range)* **then**
  Place ((EdgeWeight between those two WTs)/Range of WT) number of WTs at distance of Range in between adjacent WTs.
end

$gr_i = \{gc_i, gm_i \mid \min\{(gc_i, gm_j)\} \le AT\}$ *where* $1 \le i \le K, 1 \le j \le m$
Heuristic for Subproblem1: We have implemented an heuristic using the underlying concept of classical *geodesic K-medoid* algorithm for grouping the graph for optimized resource consumption and guaranteed latency. K-medoid chooses datapoints as medoids and works with an arbitrary matrix of distances between data points. A medoid can be defined as the object of a cluster, whose average dissimilarity to all objects in the cluster is minimal i.e. it is a most centrally located point in the cluster. We have chosen the MCS; taken from input and its adjacent SPs as first choices of medoids. With respect to those medoids initial groups are formed. In search of better group formation at

next iteration better medoids are chosen based on centrality value from corresponding existing groups.These iterative steps goes on until the process reaches to local optimality.

Subproblem 2

There is a set of groups GR. Every group will have multiple number of DMs moving through its SPs starting and coming back again to the group medoid within AT. Our aim to optimize the number of DMs required and to find out an optimal tour of it. One SP should be served only by one DM for once. We have formulated it under classical NP hard problem of MDVRP[5]. Like the cost of MDVRP here latency (L) not only should tend to be minimum but also should be within the Allowable Time(AT).

Heuristic for subproblem 2: One DM will start from group medoid. DM will choose that SP which is at shortest distance from medoid to visit. After visiting, if DM has more time left then it proceeds to visit next SP and returns back to medoid along the shortest path visiting the intermediate unvisited SPs. If DM has no more time and there are still unvisited SPs in that group left out then incur one additional DM. These processes will be repeated for all groups. This algorithm provides optimum no of DMs required for each group with their trajectory.

4. EVALUATION THROUGH SIMULATION

A. Simulation Setup: Simulation was carried out using customized ONE Simulator [6] for the area of Sundarban,India; an area of 225 sq.km was divided into 19 SPs with a density of 10 smart phones per SP, each having a bandwidth of 8Mbps and coverage range of 10m and following the Post Office Cluster movement model, which is a modification of the *Cluster Movement Model* with the Epidemic routing strategy for message transfer. In the Post Office Cluster Movement Model, the nodes come back to the SP after a fixed number of hops, which is synonymous to the working of a disaster relief team. The WTs at the group centres have a coverage range of 9 km. Our traffic model consisted of message transmission from on-field smart phones to MCS, and vice-versa. 20% of the messages generated were classified as Emergency Messages (EM), for which Sat phones/VSAT were used. Redundant paths between SPs were considered. The simulation was run for two values of AT, viz, 140 minutes and 190 minutes.

B. Results and Discussion: Our planned approach has a better delivery probability than the brute force approach by 42% as shown in figure 2. The major setback of the brute force approach can be seen from the effect on latency. Inset image shows that, there is a huge improvement of around 35 to 40 minutes(i.e about 49%) in case of the planned deployment.

Simulations [7] have been set up for 190 minutes, for both stage1 (**shelters points minimally connected via pathways**) and stage2 (**shelter points with 30% redundant pathways**). While stage1 requires 7 WTs and 11 DMs, stage 2 requires the same number of WTs & 12 DMs . It can be observed, in the suited example that the 2nd stage graph requires few(two) displacements of WTs from one SP to another due to the change in group formation for better improvement of graph compared to 1st stage. During this displacement phase of WTs; their performance slightly falls resulting a little dip in delivery probability, but improves considerably later. For details refer to [7].

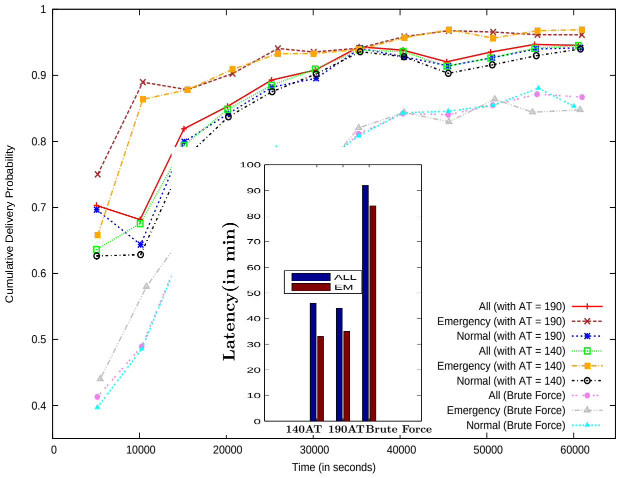

Figure 2: Time vs. Delivery Probability & Inset: Time vs. Average Latency for Planned and Unplanned Approach

5. CONCLUSION

Our design is focused primarily on ease-of-deployment, ensuring delivery probability within acceptable latency for evolving network scenario with time. Our approach towards design of ad hoc infrastructure may be useful for planning & preparedness of that area where disaster occurs frequently. The Disaster Management Organisations in these areas can devise a suitable architecture using our planned approach. The simulation results and the test bed experiments [7] reveal the effectiveness of this architecture during rescue/relief operations. Presently, we are working on the following: (1) Development of a customized interface to generate a disaster hit area map obtained through aerial survey, by integrating Google Maps and GIS maps. (2) Deployment of a test bed architecture in the area of Sundarban.

6. REFERENCES

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