A Decentralized Disaster Management Information Network *(DDMIN)* for Coordinated Relief Operations

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ABSTRACT

The objective of our work is primarily to investigate computer-mediated disaster communication system using rapidly deployable mobile computing and wireless communication technology and to realize a prototype of a Decentralized Disaster Management System & Information Network. Our Decentralized Disaster Management Information Network proposes to use concepts of heterogeneous clusters of ad hoc networks towards a technology-management solution to an issue, which is of prime concern over the ages. New concepts as well as the customized adaptations to the methods and techniques are also being used like *ETVX* and *FMEA* and a new *d-ERP* approach is proposed towards implementing a coordinated relief operations by multi- agencies.

Keywords: Disaster Management, Distributed ERP, adhoc/mobile networking, *information-fading*, *content-based network*, *narrow-casting*, etc

1.0 INTRODUCTION

The present research work extends our earlier proposed concept of 'Mobile Governance' (mGov) [1] that facilitates the enhanced technologies incorporating new management propositions including inherent aspects like effective real-time information sharing, transparency, security, implementation through wireless/mobile/AdHoc/Distributed networking schemas. The present research on the area of 'Disaster Management' forms the application of that concept. In the context of our work and scope, Disaster Management (DM) is defined as *"...a superset of direct actions and processes designed to prevent and/or lessen disastrous effects before, during and after a disaster."* Other than posing an ever-present challenge to public emergency services and ever-so-important human lives, the importance of effective DM can't be underplayed, especially in today's technologically advanced age. To address disasters in a fast and highly coordinated manner, the optimal provision of information concerning the situation forms an essential pre-requisite [2]. For the whole exercise to be the most effective and coordinated, stakeholders, players and organizations involved have to react not only efficiently and individually, but also in a coordinated manner. This highlights the need for both Intra- and Inter-Organization communications at several stages. A lack/lag in communications implies lack/lag of information flows between the level players thereby hindering the critical resource usage and its effective and efficient management. There, hence, arises a need for an Integrated Communication and Information Network for Disaster Management that provides efficient & reliable exchange with real-time processing of relevant information.

The first thing that goes off and that is so critical is the communication backbone, as in the hours and even days following an event communication is often limited because existing infrastructure was destroyed or the event occurred in an area without infrastructure. Voice service may be severely restricted because of the environmental or non-infrastructure issues. During emergencies when terrestrial telecommunication networks are damaged or severely impaired, alternative and flexible networking arrangements become critically important to ensure ongoing and effective coordination of emergency response and relief efforts. Thus, there is a recognized need for wireless communications, including high capacity wireless, for emergency management [3]. The international counter-disaster community today is increasingly considering computer-mediated networking as a powerful tool for improving disaster communications. Central to this trend is a belief that computer-mediated communications capabilities, both inter-organizations and intra-organization level, can improve disaster management practice to a large extent [4,5].

Since Disasters themselves are unstructured in scope and hence difficult to be managed centrally, there is a need for a user centric decentralized, distributed and hierarchy-independent approach wherein even the end user is empowered accordingly for quick and effective results. The main objective here is to match the available resources at any time with the needs, at the right time and to the right people. This forms our research objective in the fields of Technology enabled, real-time activated & strategically enhanced Disaster Management [6].

2.0 MANAGEMENT ISSUES AND DISCUSSION

As could be pointed out, the existence of the wireless communication infrastructure alone does not ensure efficient and effective disaster management. The existing Disaster

Management (DM) approaches are quite unstructured and are usually centralized in nature with the instructions following some sort of fixed hierarchy. This results in the poor resource management and hence causes inefficiency.

2.1 Management Structure

The principal management structure towards our DM solution is on the lines of the following:

- Identification of base model & the chief stakeholders
- Identification of the existing 'As-Is' processes
- Collection and collation of major Information flows
- Identification of best practices and research gaps
- Proposition of 'To-Be' processes against analyses above
- Simultaneous prototype design and simulations
- Dry Runs, mock drills, etc at the ground zero level

Our research aims to develop an integrated architecture and a suite of mobile applications to satisfy the above-mentioned information services in order to assist mobile teams of safety/security and emergency response-workers in crisis management during an emergency situation. The system will use advanced techniques in workflow management along with distributed information access & dissemination for effective resource management which will be integrated with location and presence services and operating transparently on wide area and local wireless networks. It is intended to run on off-the-shelf state-of-the-art mobile phones *(e.g. Nokia 9500 communicator)* or equivalent, laptops, PDAs and palmtops.

2.2 Enterprise Resource Planning

Enterprise Resource Planning (ERP) can be defined as a *"…software solution that addresses the needs of an enterprise, taking the process view of the organization to meet the organizational goals tightly integrating all functions of an enterprise."* ERP systems help to integrate the various functions of an entire organization [7]. Taking a step further, a definition of a web-enabled organization ERP was given wherein Internet was proposed to be the chief technology platform [8].

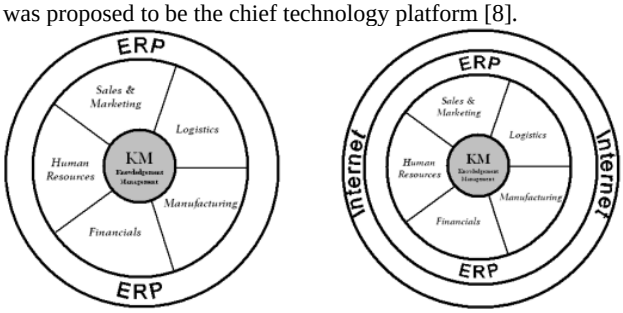

Fig. 1. Basic ERP Schematic & Adaptation of web ERP

Moving up the value chain and exploring the ERP solutions even further, we are proposing a new concept namely '*d*-ERP' (distributed ERP) in the heterogeneous environments; discussed in detail in section 3.2 ahead.

3.0 RESEARCH ISSUES

The research agenda is three fold:

(a) ***Management Roadmap:*** 'As-Is' & 'To-Be' mappings through analyses and modeling

(b) ***Technology Roadmap:*** Technological implementations, simulations and tests

(c) ***Techno-Management Roadmap:*** Strategic modeling, Feasibility Studies & Field reports

3.1 Management Roadmap

The outline of the "Management" agenda is as follows:

- Identification of major stakeholders as per the primary and secondary field research studies
- Understanding stakeholders' version of current disaster management system and the existing measurement system
- Identification of the critical entities impacted by disasters
- For each type of disaster scenario and covering each entity, chalking out the existing processes (As-Is) and sub-processes recursively to the extent we are satisfied.
- Enlisting the outputs of each of the critical processes and the inputs it requires.
- For each of the process end users, creation of specific action-sheets covering the activities before, during and after disasters.

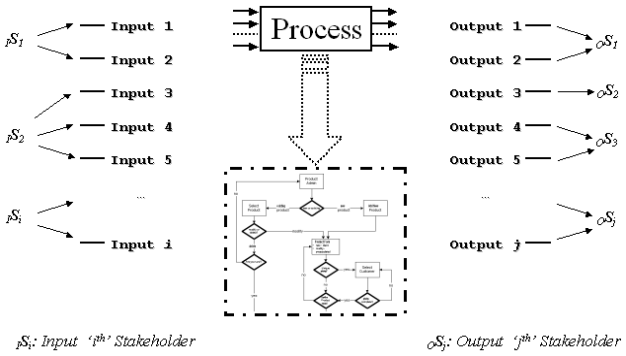

Fig. 2. Process Modeling

- Establishing test communication systems between the stakeholders and decentralizing the activities.
- Testing of proposed plans through mock drills and identification of process gaps
- Instituting a monitoring scheme, which will constantly update the activities based on the feedback from the stakeholders.

3.1.1 Analysis of Failures using FMEA: The propensity of managers and engineers to minimize the risk in a particular system, design, process, and/or service has forced an examination of reliability engineering, not only minimizing the risk, but also to define that risk whenever possible. FMEA has extracted the basic principles without the technical mathematics to give a dynamic holistic approach along with the tool committed for continual improvement [9]. The FMEA *(Failure Modes And Effects Analysis)* technique considers how the failure modes of each system component can result in system performance problems and ensures that the appropriate safeguards against such problems are in place. It is a bottom–up analytical process that identifies process hazards and evaluates possible process failures along with the risks associated with them [10]. The FMEA model is used to build a plan for reducing or eliminating the risks involved. We are utilizing the

FMEA approach as an integral part of early design process of system functional assemblies that are continually updated to reflect design changes. The analysis shall be used to assess high-risk items and the activities underway to provide corrective actions throughout the preliminary to the final design. The discrete steps involved in our FMEA approach are as follows:

(a) Define the system to be analyzed
(b) Construct the information mapping block diagrams
(c) Identify all potential items and interface failure modes and define their effect on the task to be performed
(d) Evaluate each failure mode in terms of its worst potential consequences & assigning severity classification category
(e) Identify failure detection methods & compensating provisions for failure modes
(f) Identify corrective design or other actions required to eliminate the failure or control the risk.
(g) Identify effects of corrective actions or other system attributes, such as requirements for logistics support.
(h) Document the analysis & summarize the problems

To illustrate with an example, a self-explanatory section of the FMEA analysis in the context of our System Analysis follows:

Item/ Process Step	Potential Failure/Error Mode	Potential Effect(s) Of Failure	Severity (S)	Potential Cause(s) Of Failure	Occurrence (P)	Current Controls	Detection Score (D)	RPN=SPD	Recommended Action
Pre Disaster Situation	**No Inventory**	Cannot Supply on Demand	**8**	No assessment done	**6**	No control / Need based	**3**	**144**	Assessment for minimum requirement in hand to meet disaster.
			8	No Infrastructure available	**6**	Inspections	**3**	**144**	Look for minimum infrastructure required for inventory.

Table. 1. Example model of FMEA

3.1.2 Action Items using ETVX: We are also extending the ETVX (Entry-Task-Validation-Exit) process definition paradigm that was introduced by IBM to document their processes into our approach [11].

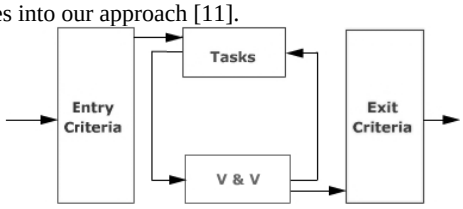

Fig. 3. ETVX Model

While 'E' stands for the entry criteria which must be satisfied before a set of tasks can be performed, 'T' is the set of tasks to be performed, 'V' stands for the verification & validation process to ensure that the right tasks are performed, and 'X' stands for the exit criteria or the outputs of the tasks. The following table illustrates a sample entry in our ETVX model of Disaster Management Information Network mappings.

Entry	Task			V & V	Exit	Time to Resolution
	Who	What	How			
- Information from District Magistrate's office - Receipt of test results from laboratory on water samples	Block Development Officer	Re-assess resources	Checking inventory, communicating with NGOs	Immediate Requirement of drinking water received	Alerted District Magistrate Office, alerted NGOs	24 hours

Table. 2. ETVX Sample Table

If an activity fails in the validation check, either corrective action is taken or a rework is ordered. It can be used in any development process. Each phase in the process can be considered as an activity and hence, structured, using the ETVX model.

3.2 Technology Roadmap

As per the existing supply-demand dynamics, our work is contributing towards the issue of touching upon the Distributed Enterprise Resource Planning (*d*-ERP) approach. As an introduction to *d*-ERP, we are working to study the multiple effects of new economy communications *(esp. Mobile/Wireless/ICT/Satellite Technologies)* under Heterogeneous atmosphere *(Geographical regions like City, Country, Continent)* as against the commonly researched upon *HOMOGENEOUS* atmosphere *(like Organizational IT impact, Industry impact)*. The main difference between the two atmospheres lies in the degree of "uniqueness" [U] and "adaptability" [A] of the target audience; e.g., in the Homogeneous environment, the degrees are: [U, A: LOW, HIGH] while for Heterogeneous environment, the degrees are: [U, A: HIGH, LOW]. As such the rules and norms are totally different in both cases and hence one can't apply the same set of rules/technology/etc of Homogeneous environment to Heterogeneous one.

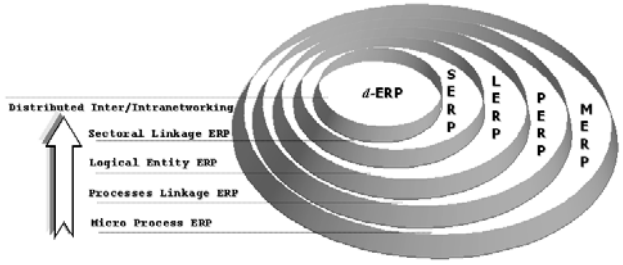

Fig. 4. *d*-ERP Hierarchy

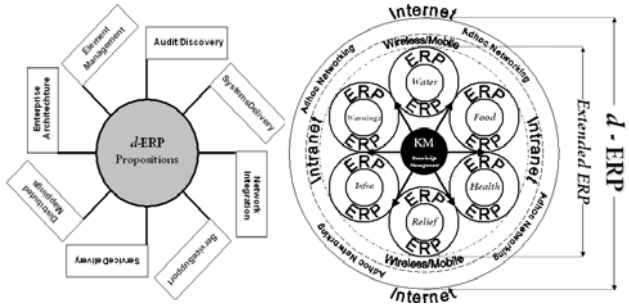

Fig. 5. *d*-ERP Propositions & DDMIN *d*-ERP layers

The enabling procedure and the structured approach would be in steps. First all the micro processes would be mapped thereby paving way for enabling the major macro processes of the logical entities (discussed in detail in section 3.3.0). Once the entire entity has been enabled on a real-time ERP, the sectors involving the inter-linkages would be taken in thereby formalizing a distributed ERP structure across regions and functional groups. In the context of our distributed solutions to Disasters and Disaster Management, which are inherently characterized by having no distinct functional components, the regular ERP approach could not be applied in this case *in toto*. Rather the setups being heterogeneous functional groups that are interconnected, there needs to be a system which can

integrate these groups in a totally decentralised and distributed manner. The critical six logical entities (water, food, health, etc) are enabled through the technological tools within adhoc networking setups, which eventually are inter-networked thereby giving a real-time Disaster Management Structure. The novel approach of d-ERP is also addressing the validity and scope of extending the definition of an enterprise by taking the heterogeneous geographical and demographic regions as a distributed one connected through a real-time network/system.

A list of the enabling technologies, taken into investigation for feasibility during the course of research, is as follows:

- Configuring the Heterogeneous Network for wireless connectivity to establish communications locally within the disaster site, within the local regions, and nationally
- Intelligent Routing Strategy for Coordinated Information Exchange in Mobile and Wireless Environment
- Handling wireless Disconnected Operations
- Topology Discovery and Location Tracking

3.3 Techno-Management Roadmap

There is a recognized need for rapidly deployable wireless communications, including wireless ad hoc networks that can be formed among the relief workers carrying handheld devices or laptops for emergency management [12,13]. However, the formation of a wireless communication infrastructure alone does not ensure efficient and effective Disaster Management (DM). In a typical DM scenario, the most common problem is the inefficient management of resources (basic commodities like food, drinking water, medicine, etc) due to poor co-ordination and lack of communication among the heterogeneous groups participating in relief operations.

3.3.1 Foundation Concepts: Upon extensive research, whereupon we proposed the concept of 'Thematic/Logical Entities,' rather than the established departments to develop our model, we found out that out of the earlier proposed eight, a couple are rendered redundant by the respondent stakeholders in the context of actual field dynamics. The six main logical entities (spanning the most critical departments/areas of functionality) being taken finally into consideration are as follows:

1. Water & Sanitation *2. Relief & Rescue*
3. Health *4. Infrastructure*
5. Food *6. Warnings*

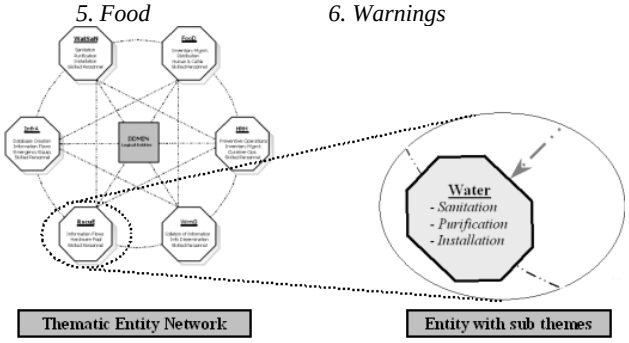

Fig. 6. Thematic Entity and its break-up

The DDMIN has three main zones: Pre-Disaster Stage *[P]*, Disaster Stage *[D]* and the Post Disaster Stage *[PO]*. Each stage has been broken into the 3-4 critical key information processes that have been researched upon through country analysis and the relevant terrain/situations. The entire information set could be depicted as [P, D, PO] and the entire probable information points, for design purposes, could be calculated as per the equation below. In the equation, E_n represents the number of entities, T_e represents the Sub-themes of the entities, Z_i represents the number of zones and C_n represents the critical information sets of information.

$$I_p = E_n T_e Z_i C_n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

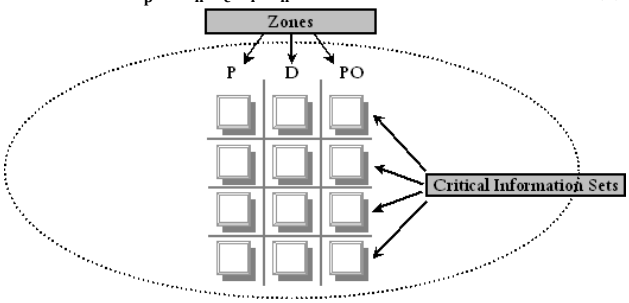

Fig. 7. DMIN internal structure

Since the number is dependent of several factors, viz., types of disaster, geographic situations, environmental atmosphere, technology spread, etc, it is indeed a huge research problem whose address promises to contribute to the immense DM proportions worldwide.

3.3.2 Schematic Architecture: The internal hierarchy design of the DMIN system is being showcased in the self-explanatory figure below as per the schematic layered structure. The pilot implementation is under process and would involve a simulated run on a particular disaster. The system being developed has benefited by the author getting the SAARC-Commonwealth fellowship towards visiting the countries where the DM systems are in place for extrapolation purposes. The benefits accruing by the DMIN are immense, given the scenario where even a 10-20 % savings of the existing losses in life and equipment during a disaster could amount to huge monetary and human values. The user feedback so far has been very good.

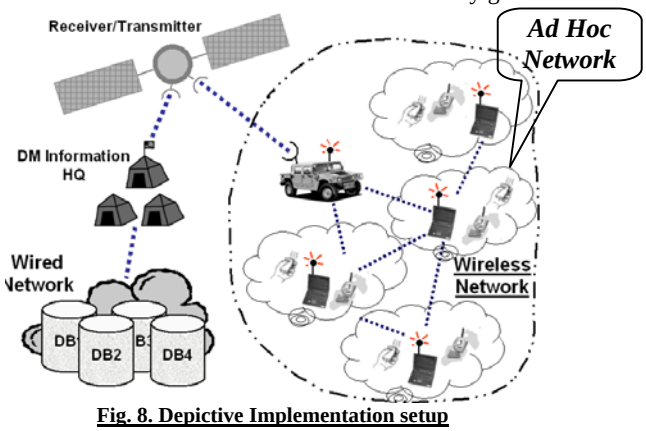

Fig. 8. Depictive Implementation setup

The proposed DMIN utilizes the concept of Mobile Multi-Agent Systems which, broadly speaking, are self-executing programs that can migrate during the execution from machine to machine in a heterogeneous network atmosphere [14]. Mobile agents are especially attractive in a dynamic network environment involving partially connected computing elements [15]. These could be effectively used for multifarious purposes ranging from adaptive routing [16], distributing topology information [17], offline messages transfer [18] and distributed information management [19]. One of the most important factors in our mobile agents' aided network is to collect all topology-related information from each node in ad hoc wireless network and distribute them periodically (as updates) to other nodes through mobile agents [20]. Once topology has been mapped, the other two relevant aspects remain as Information retrieval and Information dissemination taking in the concepts of link stability, information aging, etc.

A centralized management is characterized by restricting important decisions to one or a few nodes on a given sub-network wherein these special nodes become performance and administrative bottlenecks in a dynamic system [21]. A decentralized and fully peer-to-peer architecture like ours, on the other hand, offers potential advantages in scalability as also the scope. There is a growing interest in using mobile agents as part of the solution to implement more flexible and decentralized network architecture [22,23]. DMIN uses Flags/Emails/SMS for both off-line messaging and on-line instant messaging schemes [17]. While the front-end is being made simple to use for obvious reasons, the back end of the proposed application is highly complex with regards to the issues involved like complexity of the systems involved, networking issues, algorithms involved and the technology frontiers.

Our work underlines the need and importance for the content based searching as well as routing in the context of a fully distributed Decentralised Disaster Management Information Network (DDMIN). For example, let us assume that a relief worker urgently requires some amount of cholera vaccine. In such cases, there is a high need of getting right things in right amount at right time from a right place i.e. a place that is physically near and accessible in such an emergency situation. In a distributed network with only wireless connectivity and no centralized control, these kinds of random searches (the node issuing the query have no prior idea about the location of the destination) can only be handled using content-based routing scheme.

3.3.3 Networking Concept: While using the ad hoc networking strategies and implementations, we have developed an intelligent multi-hop information retrieval system supported by a ***content-based*** network, where the query itself will lead the search process to get the proper information from the nearest available destination through the novel concept of utilizing a two-layered approach of content-based searching using ***narrow-casting*** superimposed over a broadcasted ***information-fading*** layer. The objective of *information-fading* is to make a node aware of information content of other nodes in the network through broadcast-based multi-hop percolation of information; however, the preciseness of knowledge about a node decreases or fades away with hop-distance, thus reducing the information overhead. The term fading of information actually implies propagation of progressively summarized information based on a semantic classification of information. In such a knowledge-network, our content-based query retrieval process becomes quite effective and uses *narrow-casting* (vis-à-vis broadcasting) to access the prospective destination through the relevant set of nodes only.

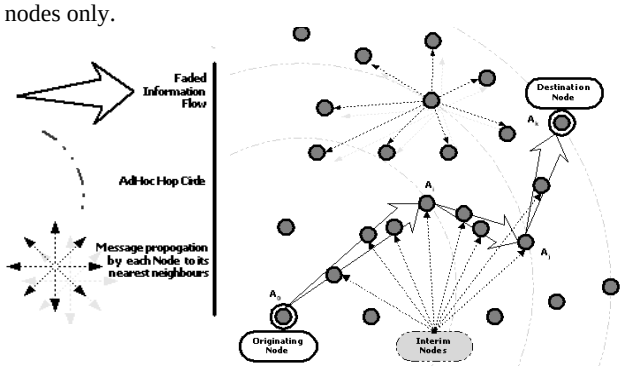

Fig. 9. Typical dynamics of information flows/retrieval

The per-hop narrowing of the search space will eventually reduce the unnecessary visit of irrelevant nodes. The benefit of narrowcasting with information fading will be more pronounced in large networks and with frequent searches. The scaling down factor is tremendous with the running results showing a remarkable reduction in the search domain by a factor as high as 2.5 times.

4.0 METHODOLOGY ADOPTED

The methodology towards our research is a mix of structured questionnaires, unstructured interviews, country case studies, regional case studies, interactive discussions with the stakeholders and technological development including simulations. The results are validated through direct feedback from respondents (stakeholders). Sampling is done as per the standard approaches.

5.0 CONCLUSION & FUTURE SCOPE

This paper outlines the research work being carried out and under completion in the context of real-time Disaster Management through latest management techniques and adhoc networking as enablers. While we have incorporated the mobile technologies in the DMIN set-ups, the prime issues of interest remain as the Service Delivery, democracy, governance and law enforcement [24]. Application development is another aspect that has an immense scope for research. The applications as also the end product should be so developed so as to take into account the literacy levels, technology adaptability, ease of usage, effective GUI techniques, etc. Standards of technology, effective bandwidth allocation and full potential of the wireless/mobile applications are some of the most important aspects [25] as also the security and authorisation policy matters.

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ACKNOWLEDGEMENTS

This research has been sponsored and recognized by the **International SAARC-Commonwealth AMDISA Fellowship Committee** & **Indian Institute of Management Calcutta**. Thanks are due to the governments of **India, Sri Lanka, Bangladesh, Nepal, Thailand** & **ADPC centre, Bangkok** who have recognized the research and are helping in primary & secondary information collections and other areas. Help and guidance from resourceful individuals are also being acknowledged in addition to international NGOs like **OXFAM, UNDP, CARE, SPADE, ABCD**, etc.