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Link Fault tolerable Network Topology for Network services provision in Disaster area

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Abstract

The drift change in weather and wars among countries changing the map of world rapidly and their result are too much dangerous. Aftermath the mass destruction of natural disaster or war, the communication infrastructure might be smashed completely or partially and would not be able to support the requirements of rescue operation. In this research paper we have proposed a link fault tolerable network topology for network service provision in disaster areas. In proposed framework methodology all HAPs connected with each other in mesh network topology, in Star topology with satellite and point to point with WiMAX ground stations. All HAPs have multiple hot backup links, which will become active in case of congestion or active link failure. The proposed hybrid network topology evaluated in comparison with hierarchal network topology in context of infrastructure. The results of evaluation proved that hybrid network topology is better than hierarchal network topology in terms of link redundancy, link utilization, end to end delay and throughput. In terms of link redundancy and link utilization, Hierarchal network topology have only limited backbone links while proposed hybrid network topology multiple redundant links which will not only increase the consistency and reliability also reduce the load on individual links. All simulations are performed using Optimized Network Engineering Tool (OPNET).

Keywords: Backbone link, emergsat, HAP, mesh link, REMSAT, terrestrial network, WLAN, WiMAX.

Introduction

The internet has become an essential part to everyone's daily life. The demand for broadband access has grown gradually, as users experience the convenience of high-speed responses combined with "always on" connectivity. Among the different kinds of telecommunication technologies, wireless communication has become one of the most attractive ways to connect information highways with people either staying at home or on the move and it becomes an essential part in the modern life of technologies.

In disaster areas rescue and other life-saving operations completely depends on Reliable, efficient, and fast emergency communications system. During the disaster all the terrestrial based networks may be partially or totally shutdown[1]. As during North Pakistan earth quack[1], Pakistan flood[1], Hurricane Katrina[2-5], California Wildfires[6], Taiwan Earthquakes in 2006[7,8] and Hurricane Gustav in September 2008[9]. Research on satellite communications has proved that satellite communication is very helpful and reliable during the disaster rescue operations, when no communication channel available, like European projects Real-Time Emergency Management via Satellite (REMSAT) and Emergency Management by Satellite Communications (EMERGSAT)[10]. Although satellite links provide high speed connections in such critical situations for immediate rescue response[11], but only limited number of people can avail satellite compatible devices for communication. Similarly satellite communication is costly and faces too much delay as compared to the territorial based data networks.

High Altitude Platforms[12] integrated with a wireless technology can be use as alternative to satellite and terrestrial based communication[13,14]. HAPs design especially to operate at stratospheric altitudes, from 17 to 50 km approximately[15,16]. These platforms are reusable, stay for years in, closer to the Earth as compared to satellites[11], no proper launching requirements and also do not require space qualified specific hardware. The first giant balloon launched by bell laboratories in 1960 for telephone services in America[11]. HAPs provide high bandwidth with low delay and latency as compared to satellite and support to all wireless technologies[14]. HAPs are potentially suitable for new wireless broadband services[11] like for mobile phones, for disaster relief and military operations with rapid deployment feature[17].

Wireless LAN[18-20] and WiMAX[21] are the two most suitable technologies for disaster scenarios, because of their hardware availability in every device like Cell Phones, PDAs, TABs, and Laptops. WLAN support up to 300Mbps[22] and cover limited area in meters while WiMAX cover up to 70 kilometres area and support up to 300+ Mbps speed with high speed mobility as well[21] also eliminate Last mile wired infrastructure and wired backhauling[21]. Providing WiMAX from HAPs is a novel approach and some researchers have been done work to show the effectiveness [11,23-26].

In this research paper we have proposed a Link Fault tolerable Network Topology for Network services provision in Disaster area. In this topology Every HAP has multiple backbone connectivity, one link from ground station, one link from satellite and Mesh among HAPs. These links not only work as hot backup links also shared the overall load of network. The proposed hybrid network topology evaluated in comparison with hierarchal network topology in context of infrastructure. All simulations performed in OPNET.

Related Work

Many researchers have done work on HAP based networks for different situations like, HAP Based cellular communication[27], HAPs use in Australia[28] coastal monitoring, surveillance, climate monitoring, emergency communication services, WiMAX using HAPs[24,29] and use of Hap during Katrina hurricane & tsunami[30].

WiMAX Enabled HAPs-Satellite Hybrid systems[14] has been evaluated by comparing different network architect of Hybrid systems, HAP-HAP, HAP-GEO and HAP-LEO-GEO on the base of Delay, Response time, throughput and Traffic capacity by the provision of typical services. Delay and response time is lesser[14] in HAP-HAP scenario while highest in HAP- LEO-GEO scenario. Although all the HAPs connected in mesh topology but the main backbone link is only one which is main draw back in this topological configuration. If ground station of WiMAX link goes down due to the re-occurrence of the disaster then the both symmetric and asymmetric topological configurations will failed which is not a suitable network topology for such critical network.

An integrated Aerial Telecommunications Network (ATN) architecture for emergency communications based on multi level hierarchal topology has been proposed[31]. This multilevel hierarchal topology based on HAPs and LAPs divided into clusters and support typical services required for emergency conditions. Controlled mobility[31,32] used for links failure recovery. Although this network has multiple backbone links but support up to some extend to link failures and the involvement of HAPs and LAPs on different levels not only increase the cost also the hop count which leads to high delay and low performance.

Emergency Medical system[33] prepared to tackle the emergency conditions immediately after the natural disaster. Practically two tethered LAPs with IEEE 802.11a/b/g[20]used as for communication at altitude of 661m. IEEE 802.11a used as backbone Link from ground station to sky station, while IEEE802.11b/g[20] used for clients access. Foot print 78.54sqkm[33] divided into three sectors using directional antennas at 120°. This was a standalone ADHOC type network which can be utilizes for small scale disasters and not suitable in thunderstorms or in high speed air. Used Tethered HAPs could not stay more than three days in space. This network may also not work in population congested areas due heavy load on network.

Disaster-tolerant and dependable network system[34] based on Nerve Net[34,35]. The network architecture consists on terrestrial sites based Wireless access points, Sensors, Unmanned HAPs and Satellite Links. Terrestrial sites connected in wired mesh topology, while unmanned aircrafts used as backup bridge link provider if the mesh network links break down. This solution also not fit in all scenarios where the entire terrestrial based network smashed and disaster may occur more than one time.

Shelter communication[36,35] and trans-locatable[36] concepts implemented in Higashi-Matsushima City for disaster recovery after Great East Japan Earthquake and the resulting tsunami on March 11, 2011[36] for rescue operations. IEEE802.11b/g based terrestrial base stations with directional antennas used. Backbone was based on wireless multi-hop concept using IEEE 802.11b and 25-GHz band NTG - 2500[36]. IEEE 802.11g use as last mile for coverage of 30sqkm area. The network availability was not more than 8 hours in day and only fit in implemented scenario.

“Hastily Formed Networks (HFN) are portable IP-based networks which are deployed in the immediate aftermath of a disaster when normal communications infrastructure has been degraded or destroyed”[37]. HFNs based on three layer model[37], while the actual deployment and configuration depends on the actual situation of disaster. Aftermath of earthquake Haiti[14,37,38] in January 2010, HFNs used as communication network until and unless the networks restored. Urban Shield[37] exercises also used private secure HFN. Although the proposed is very well for disaster situation but no topological configuration defined for the proper, reliable, and fault tolerable network deployment.

Methodology

The goal of the research is to find out fast deployable, efficient and reliable network topology with redundant backup links to cover the link failure and congestion situations. All the simulations performed in OPNET[39]. The complete simulation based on Components, Satellites, Internet cloud, High Altitude Plate forms, Servers, Routers, WiMAX and Satellite ground stations, WiMAX –WLAN Routers, Links, and Client end devices and required services like, Email, Web, FTP, Voice and Video Services etc.

Considered a the disaster area of 40sqkm, where all terrestrial communication system (GSM / WIMAX / Landline / WLAN etc.) has been fully smashed and no more communication channel available. To start rescue operations a quick, reliable and easy deployable network setup is required which accessible for affected people, rescue team and media for proper communication. All Rescue teams, shelter & medical camps and equipment have direct access to WiMAX network for communication. It is supposed that the affected people have both WLAN and WiMAX supported devices, the WiMAX users will directly connected to WiMAX enabled HAPs while WLAN clients connects to WLAN network which is backboned from HAPs using WiMAX Backhaul links.

In simulation configured parameters of WiMAX-Enabled HAPs, WiMAX links and subscribers are described in table-1 and different type of used scheduling service for different applications shown in table-2.

Table-1
WiMAX Global Configuration parameters

Parameters	**Value**
PHY Profile	Wireless OFDMA 20MHz
Path loss Parameters	Vehicular
Efficiency Mode	Mobility and Ranging Enabled
HAP Cell Radius	10 km
HAP Altitude	20 km
HAP user capacity	500 users
Backbone Point to Point Antenna	Directional
Max, m Transmission Power of HAP	20W
Maximum Transmission Power of P-P Module	20W
Maximum Transmission Power of SS	0.5W
Modulation Coding Schemes (MCS)	QPSK ½

Table-2
Scheduling Service Classes and applications

Services Class	**Application**
Unsolicited Grant Service (UGS)	VoIP
Enhanced Real-Time Polling Service (ertPS)	Video conferencing
Non Real-Time Polling service (nrtPS)	FTP
Best effort (BE)	Data transfer & Web

Topologies: There are two types of topologies which evaluated in the research paper. i. *Hierarchical* Network Topology. ii. Proposed Hybrid Mesh Network Topology: Mesh Topology among all HAPs, Star Topology with satellite, Point to point with working base station near to the disaster site.

In this topological configuration all the WiMAX enabled HAPS connected in a hierarchal way. HAP_1 directly connected to satellite and a nearest available WiMAX ground station node (WiMAX_GS), which further connected to Internet cloud. The WiMAX Backbone links of HAP_1 from WiMAX_GS performed as active link, while the link between Satellite and HAP_1 performed as a hot backup link. All the other HAPs connected to internet and rescue head quarter via HAP_1 and all type of traffic passed through HAP_1. If both backbone links associated with HAP_1 failed then HAPs will lose connectivity with Rescue data centre and internet. In Data enter all the servers connected to a Main Layer Three switch which directly connected to internet cloud. The major flaw of hierarchal topology is the single point of failure, which not acceptable in critical networks. The detailed schematic and simulated diagram has shown in figures 2 and 3.

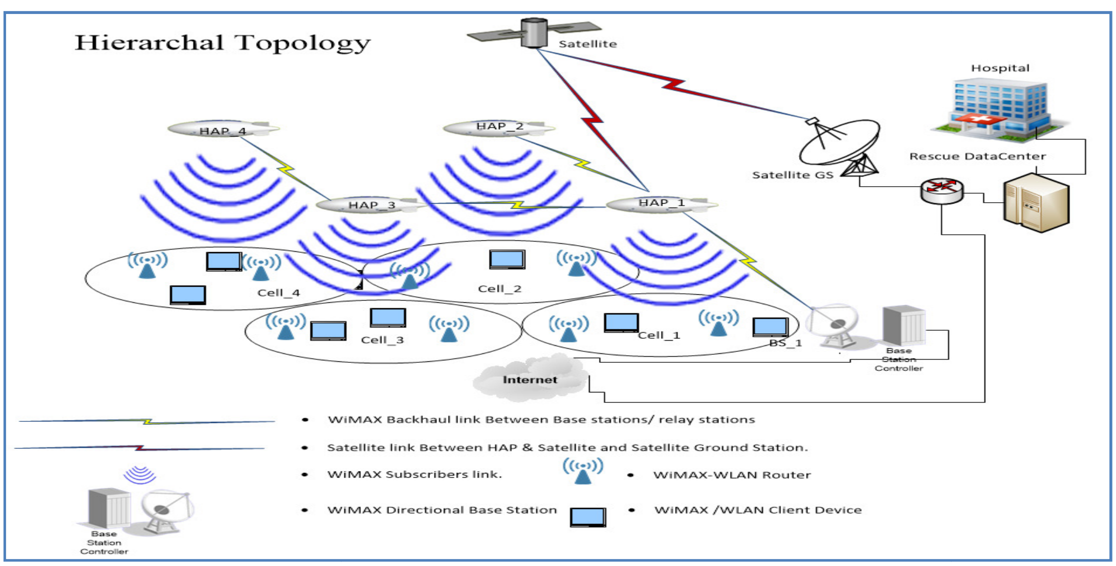

Figure-1
Schematic Diagram of Hierarchal Topology

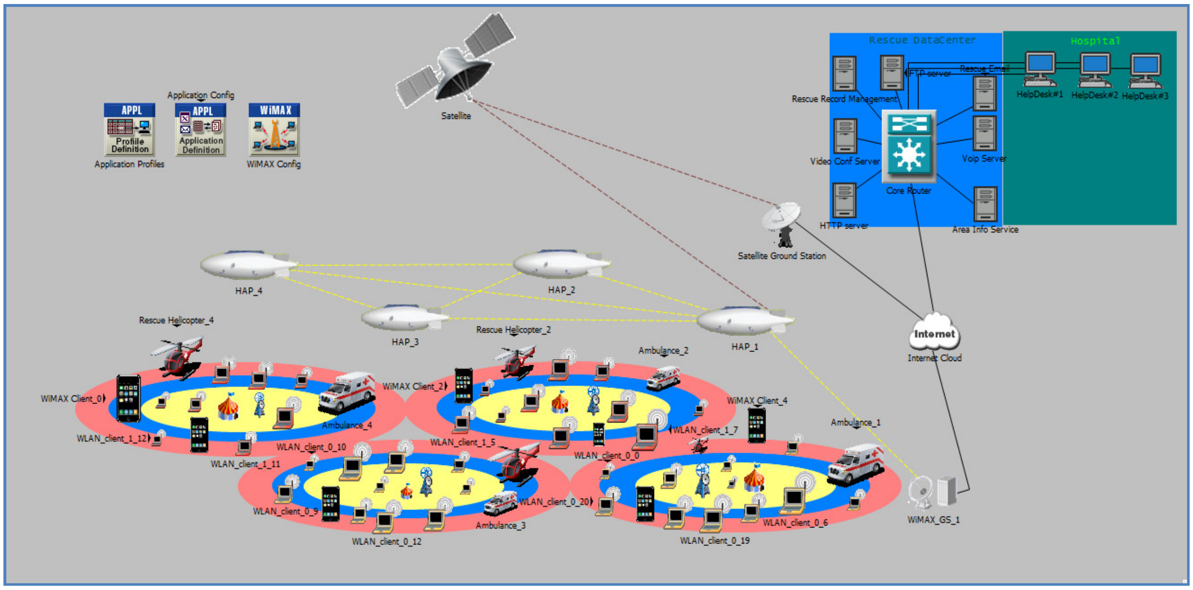

Figure-2
Simulated Diagram of Hierarchal Topology

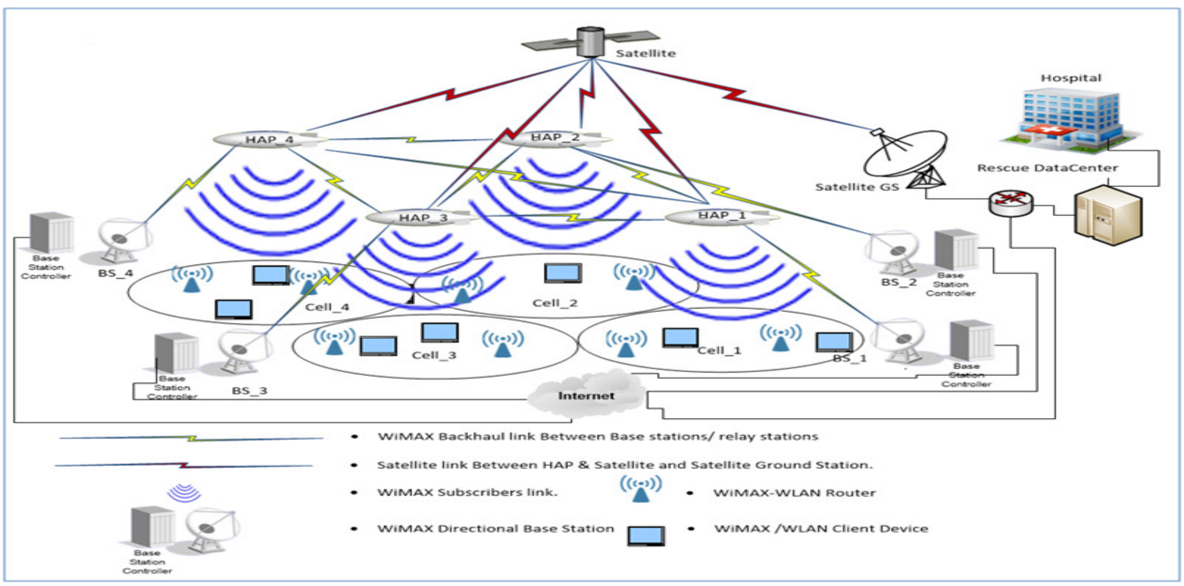

Figure-3
Schematic Diagram of Hybrid Mesh Topology

In this topological configuration Every WiMAX enabled HAPS have multiple backbone links, one point to point backbone link from WiMAX Ground station, Second satellite point to multi point link from satellite and multiple WiMAX links from different HAPs. All the Inter HAP and satellite links performed as hot backup Links, while the all WiMAX Point to point links from WiMAX Ground stations performed as active links. If active links of HAP failed or congested due to load then the traffic of that HAP will be automatically routed through backup link. In this topology not only the overall load of network distributed among all link, also removed the dependency on a single link or node. This increased the performance of the network and network became link fault tolerable network. The Data centre network topology remained same as in hierarchal topology. This topology is most appropriate network topology for the network deployment in disaster area and provisioning of different services. . The detailed schematic and simulated diagram showed in figure-4 and figure-5.

Performance Evaluation: Both Hierarchal and Hybrid network topologies simulated on same parameters in OPNET and evaluated in context of link utilization. Both simulations run for 1200 seconds to evaluate the proper link utilizations and traffic switching from active link to backup link.

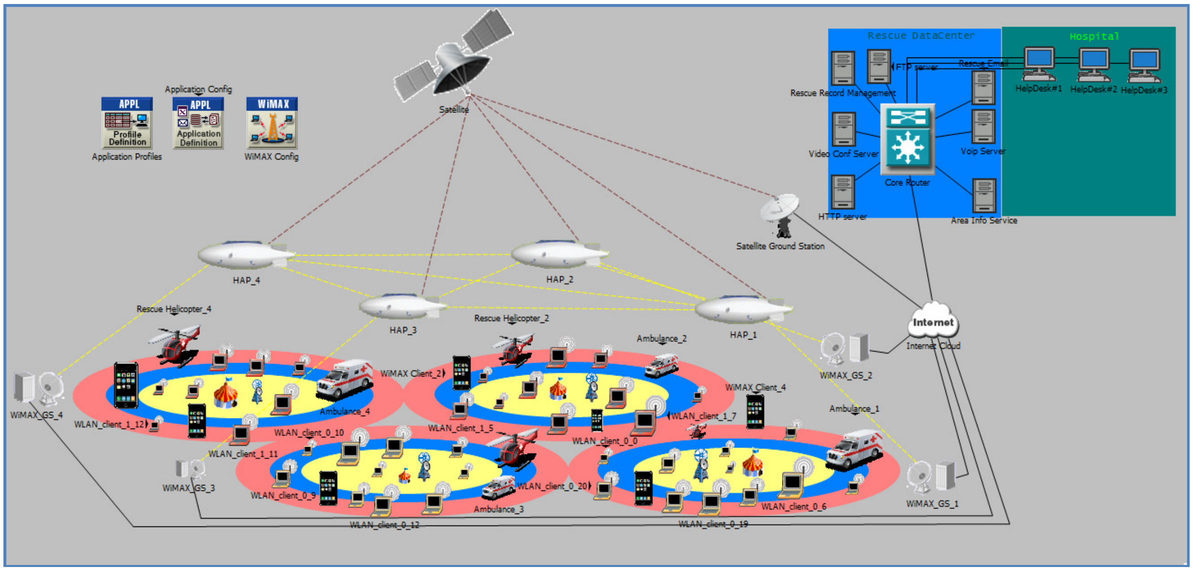

Figure-4
Simulated Diagram of Hybrid Mesh Topology

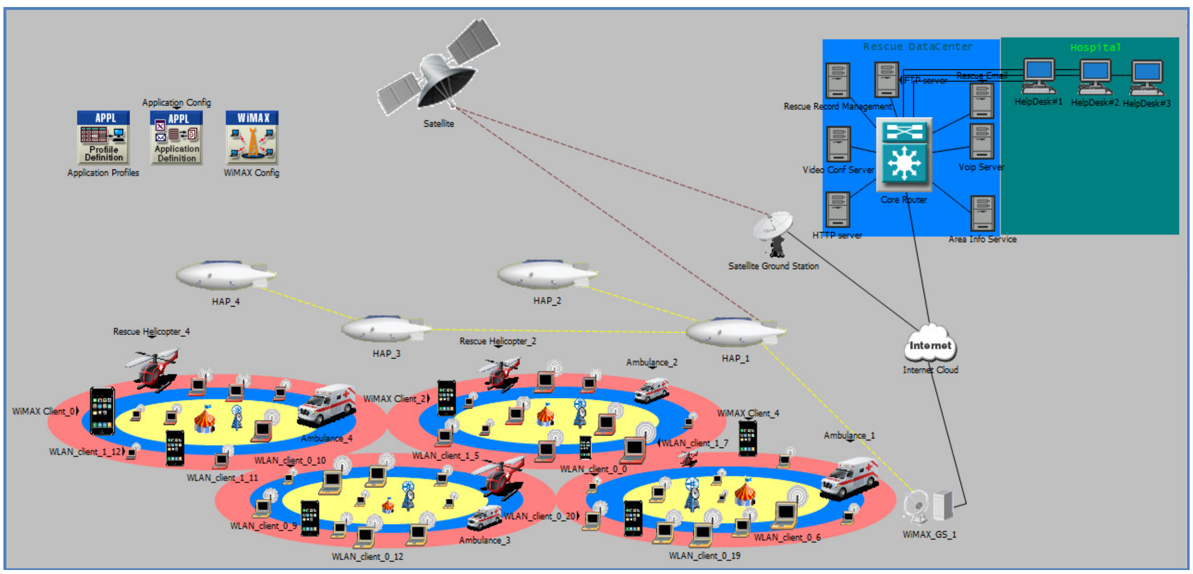

Figure-5
Hierarchal Network Topology

In this configuration HAP_2 & HAP_3 directly connected to HAP_1, while HAP_4 connected via HAP_3 with HAP_1 and HAP_1 has two backbones links, one from WiMAX Ground Base station and second from satellite. WiMAX link act as active link, while the Satellite link act as hot backup link. This configuration has failover backup connectivity which make network link fault tolerable up to somehow for backbone links. The traffic can pass through one or both links depends on load and link status of active link. As shown in figures 6 and 7.

According to the results in figure-7: i. Links HAP_4 ↔ HAP_3 and HAP_2 ↔ HAP_1 have utilization ≈1.4% and ≈1.5% respectively because these only have load of their own clients. ii. Link HAP_1 ↔ HAP_3 has utilization ≈2.5% because it bear the load of HAP_3 and HAP_4, while the link satellite ↔ HAP_1 has utilization ≈5.5% because all the traffic passed through this link. iii. All traffic passed through active link HAP_1↔WiMAX_GS_1. iv. In congestion or Failure of link HAP_1↔WiMAX_GS_1 traffic switch to backup satellite link. v. In this scenario 50% utilization of all links the both main links HAP_1↔WiMAX_GS_1 and satellite link will be congested and network can chock. vi. This situation is also not favorable for critical networks.

In Hierarchal network topology WiMAX link from ground station failed due to the re-occurrence and expansion of disasters while the backup satellite link failed due to fault in satellite module of HAP-1 which also effect the overall performance of hierarchal network topology badly and no connectivity remained between clients and Data enter. As shown in figure-8.

According to the results in figure-9: i. After traffic switching from HAP_1↔ WiMAX_GS_1 to HAP_1 ↔ Satellite. At 700 seconds satellite module of HAP_1 also failed. ii. As satellite link failed HAPs connectivity with Datacenter and internet failed. iii. This situation is also not favorable for critical networks.

Similar to backbone link HAP_1, the backbone links of other HAPs also can fail and if the backbone link of any other HAP failed then there is no redundant link for that specific HAP. This also leads to the instability of the topology in critical networks.

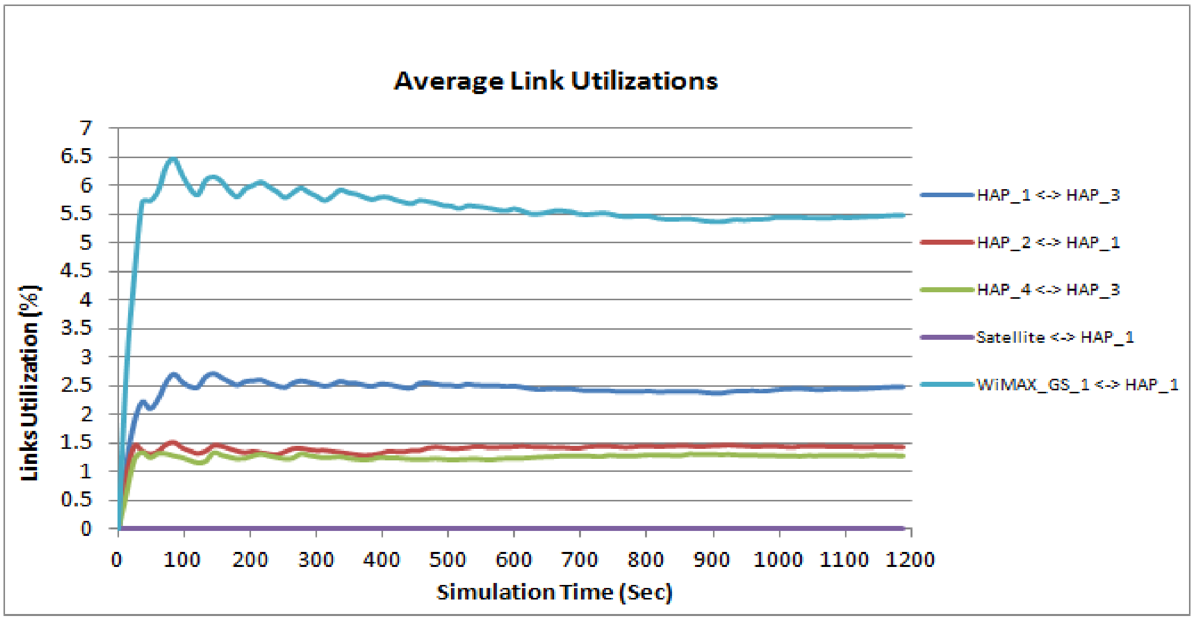

Figure-6
Performance of Hierarchal Network Topology

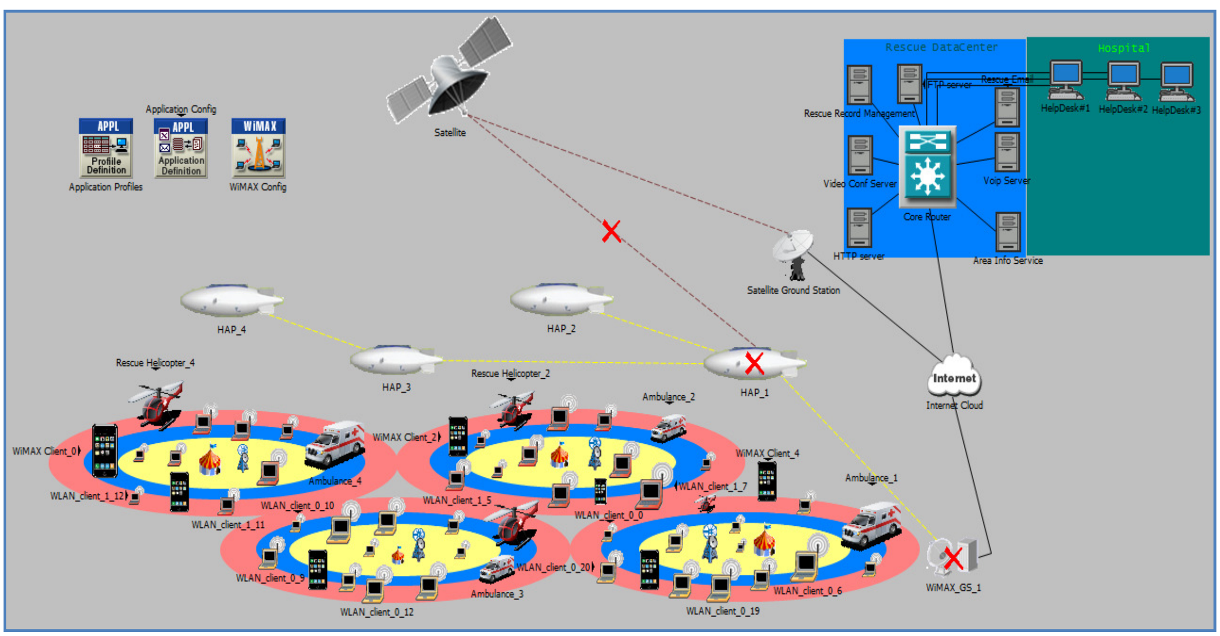

Figure-7
Links Failure in Hierarchal Network Topology

Hybrid Network Topology: In this configuration the topology designed in such way that network has multiple WiMAX and Satellite based backbone links. ALL or some HAPs directly connected to their Respective WiMAX ground stations as well with satellite using satellite point to point links. According to this topological configuration the topology provide the maximum link fault tolerable network with maximum backup of each backbone link.

In this configuration all WiMAX links are Active links while all satellite and inter HAP WiMAX links are HOT-Backup Backbone links which will not only provide connectivity in the absence of active links also share the load of network in routine and congestion. If any HAP complete goes down only related coverage area will be effected and other topology work same as with some changing in routing. This topology is reliable, fault tolerable and load balanced topology as compared to hierarchal network topology. Although this topology may be leads to increase the cost of network but for the saving of lives cost does not matter. Detailed simulated diagram shown in figures 10 and 11.

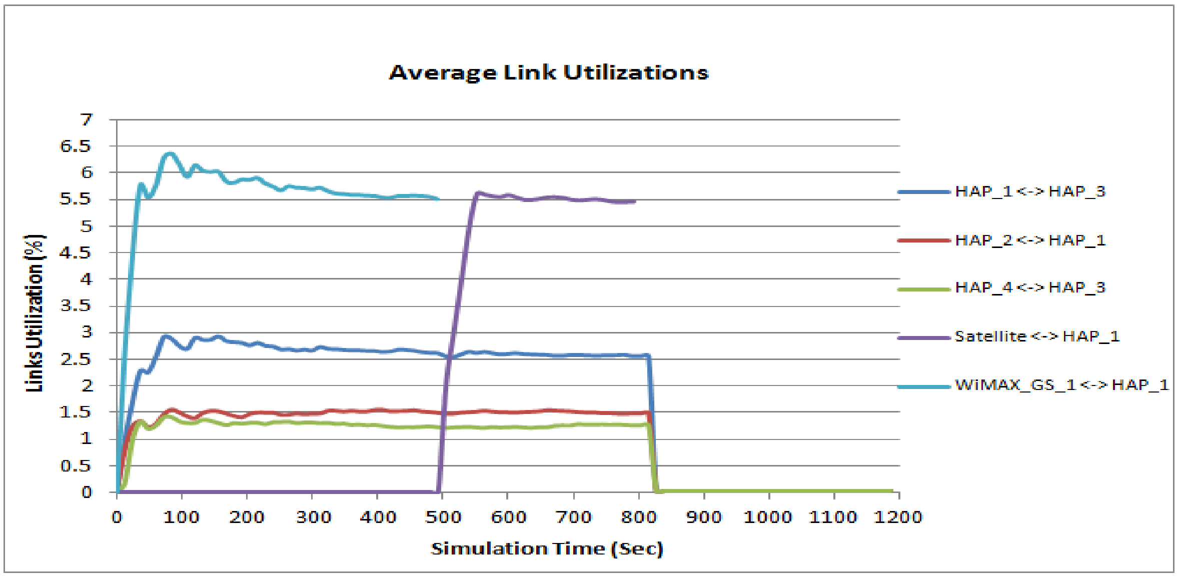

Figure-8
Link Failure effects on Performance of Hierarchal Network Topology

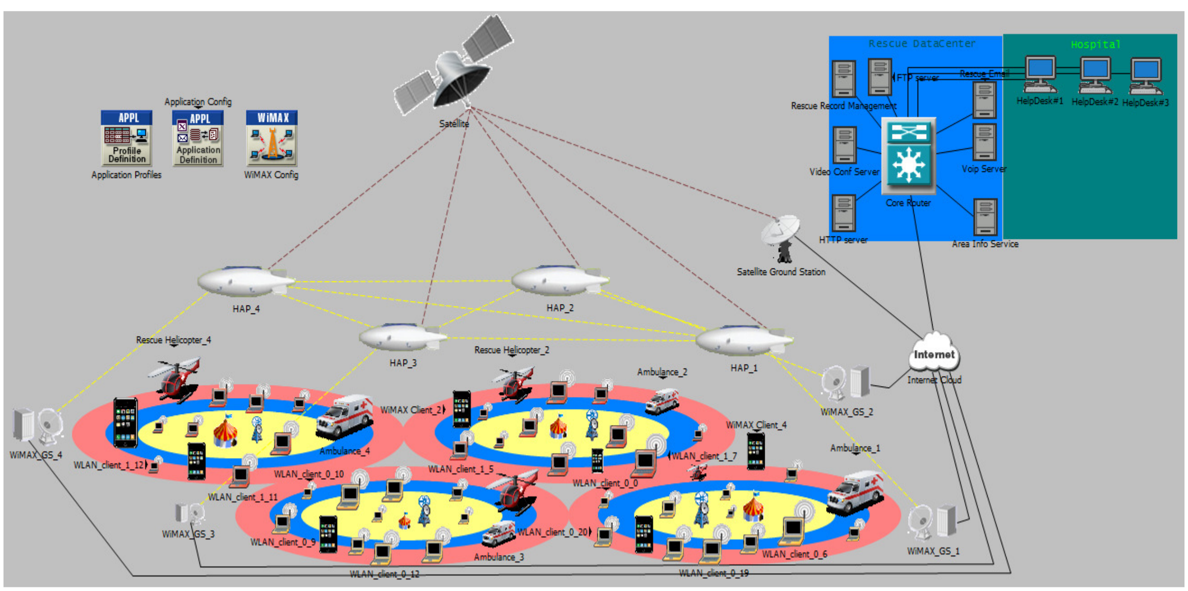

Figure-9
Proposed Hybrid Network Topology

According to the results of figure-11: i. Active links in this topology are from HAPs to their respective WiMAX ground stations. ii. Links among HAPs performed as hot backup links. iii. Links between HAPs and satellite performed as hot backup links.

All active links utilization is near about equal because these bear load of their respective HAPs.

As discussed already that in Hybrid network topology each HAP has multiple links from different sources. WiMAX links from ground stations failed due to the re-occurrence and expansion of disasters, after failure of active links, backup links became active and traffic routed through backup links. After some time the three backup satellite links failed due to fault in satellite module of HAP-1, HAP-3 and HAP-4 while the satellite link of HAP-2 remain up and complete traffic of topology routed through this link with the help of inter HAP WiMAX links. After the failure of seven main links the topology remained active and clients accessed the services with little bit increase in delay and degradation of performance. As shown in figures 12 and 13.

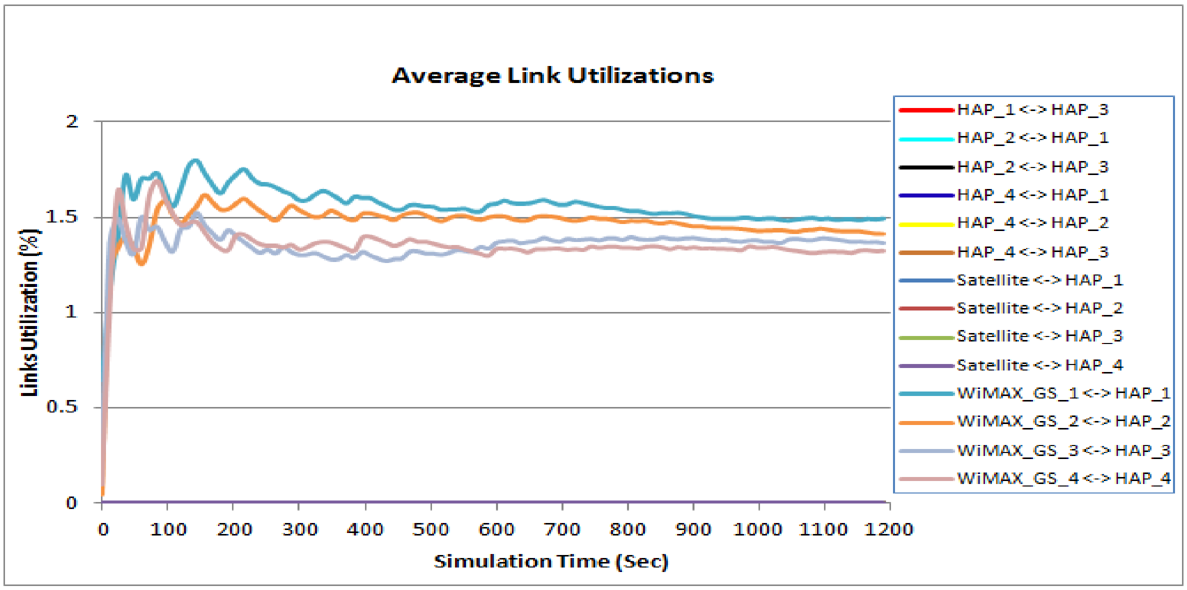

Figure-10
Performance of Purposed Hybrid Network Topology

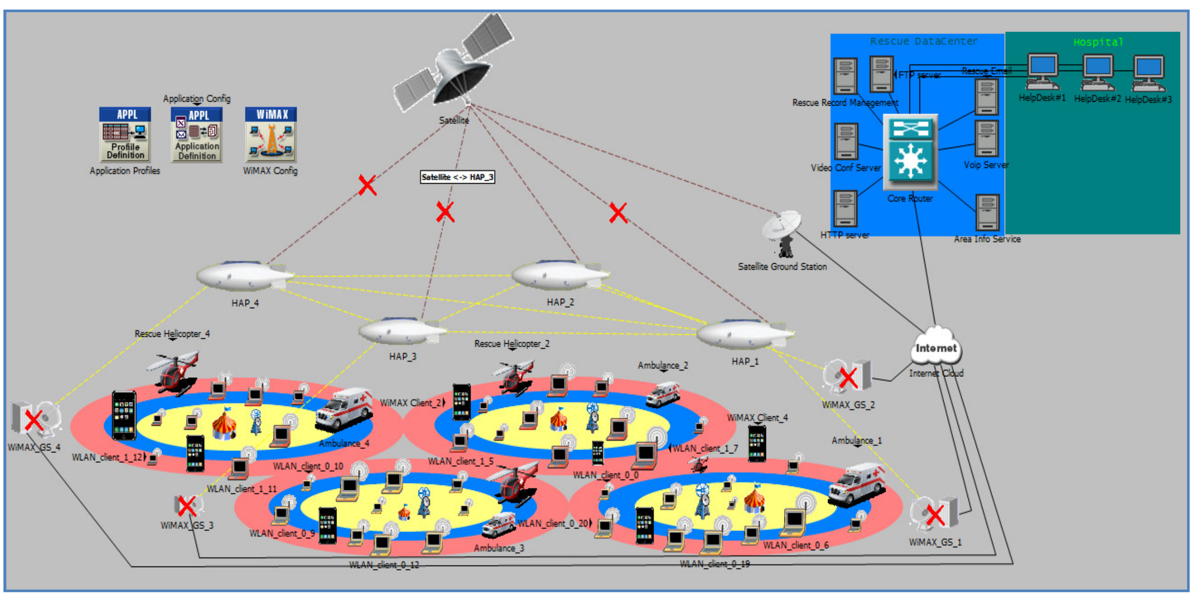

Figure 11
Links Failed in Hybrid Network Topology

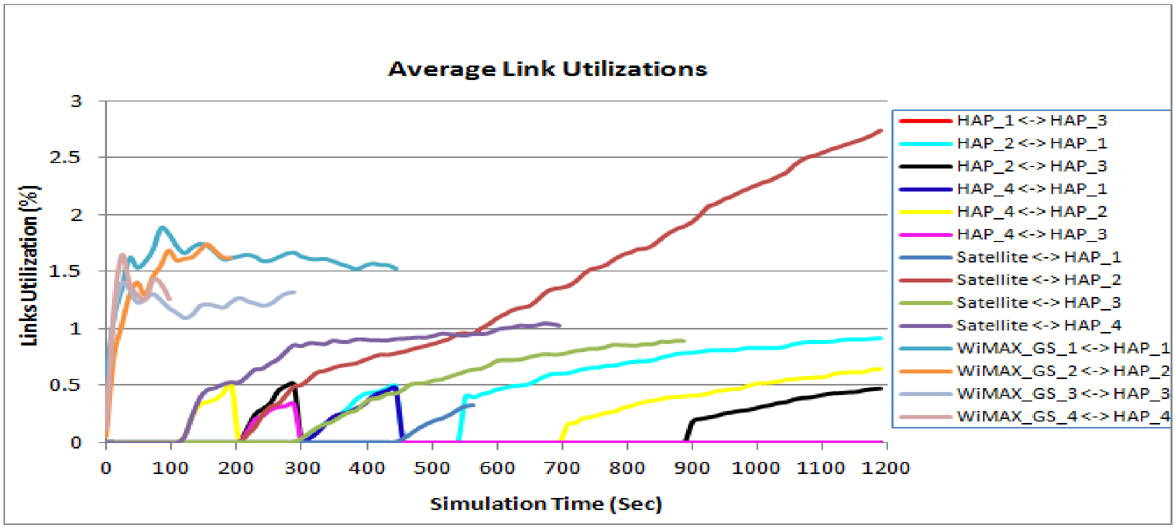

Figure-12
Link Failure effects on Performance of Purposed Hybrid Network Topology

According to results shown in figure-13: i. When Link WiMAX_GS_4↔HAP_4 failed at 100 second Backup link Satellite↔HAP_4 became active and some traffic route through this link and some from HAP_4↔HAP_2, ii. When link WiMAX_GS_2↔HAP_2 failed at 200 its Backup Links Satellite↔HAP_2 and HAP_2↔HAP_3 became active and traffic routed through these links mean while the traffic route of HAP_4 change from HAP_4↔HAP_2 to HAP_4↔HAP_3. iii. When Link WiMAX_GS_3↔HAP_3 failed at 300 seconds its backup link satellite↔HAP_3 became active and its all traffic route through this link, mean while the traffic route of HAP_4 and HAP 2 change from HAP_4↔HAP_3 and HAP_2↔HAP_3 to HAP_4↔HAP_1 and HAP_2↔HAP_1 respectively. iv. When Link WiMAX_GS_1↔HAP_1 failed at 450 seconds its backup link satellite↔HAP_1 became active and its all traffic route through this link. v. When Satellite module of HAP_1 failed at 575 seconds then HAP_2↔HAP_1 became active and all the traffic of HAP_1 routed to this link. vi. When Satellite module of HAP_4 failed at 700 seconds then HAP_4↔HAP_2 became active and all the traffic of HAP_4 routed to this link. vii. When Satellite module of HAP_3 failed at 900 seconds then HAP_2↔HAP_3 became active and all the traffic of HAP_3 routed to this link.

From the above evaluated results, it is concluded that in the above proposed hybrid topology although many links or modules failed but mean while there are also backup links available in the topology which support the consistency of the network topology and topology sustained till the end of time. So this can say a link fault tolerable hybrid network topology for disaster areas and critical networks.

Conclusion

Proposed hybrid network topology based WiMAX enabled HAPs-Satellite integrated system is suitable for disaster areas where the communication network failed totally or partially. The main objective of this work is to propose and analyze, evaluate the link fault tolerable Hybrid network topology for provision of IP Based service in disaster area. Both Hierarchal and Proposed Hybrid network topologies evaluated performance wise in context of infrastructure. All the results proved that proposed hybrid network topology is better than hierarchal network topology. Hybrid network topology have multiple backup redundant links which not only shared Load also acted as backup of each other's, while in hierarchal network topology every HAP has only one backbone link and in case of failure of that single link HAP's connectivity with network loosed which not suitable situation for such type of critical networks. In proposed Hybrid network topology, in case of link failure delay and response increased slighter in the coverage area of associated HAP's due to the switching of traffic from active link to backup link, while the overall delay and response time remain un-changed, which is not possible in hierarchal network topology. Hence according to simulations results, Proposed Hybrid network topology is very suitable for such type of critical networks.

Future Work: i. Proposed hybrid technology although provide the backup links for sustainability. It would be extend by work on the backup of HAPs to for complete fault tolerable network setup in disaster areas. ii. It would be integrate with already deployed and partially saved GSM /CMDA/UMTS or any other technology network to use in disaster area, which will be very helpful for the local residents and they will no need to change their mobile phones or customer premises equipments. iii. Proposed network can integrated with high speed Wireless optical links to increase the bandwidth, which not only increase the overall performance of network also remove the bottleneck of congestion due to overload and availability of only single backbone link. iv. Energy/power is a major concern in disaster areas; it can improve for energy conservation of client end devices for long backups. v. Multi technologies (WiMAX & WLAN) supported devices needs handovers from one technology to another on the basis of service availability, proper Handovers management in such type of networks required. vi. HAPs based networks can utilize for pre-disaster announcements for safety and preparations.

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