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SATELLITE BASED DATA COMMUNICATION: A SURVEY

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ABSTRACT

Satellite communication is well known in providing best services where broadcasting is essential, where terrain is hostile and very sparsely populated. It also has niche where rapid deployment is very critical and important. In Global Network Infrastructure satellite is considered as an inseparable component of the communication infrastructure. A variety of research work has been explored and published for satellite based data communication & networking. It is utmost important to conduct a survey on different aspects and research issues of satellite based communication with a focus on the latest development. In this paper, we summarize, compare & comments on the approaches proposed for the satellite based data communication with keeping in view the parameters like Quality of service, Interplanetary Internet, Mobility management, explicit load balancing and packet reordering issue.

Keywords: Communication, Explicit Load Balancing, Interplanetary Internet, Mobility Management, Quality of Service, Satellite.

I. INTRODUCTION

Satellite communication is used in a number of fields, e.g. to provide trunk links for network service providers and temporary communication systems in emergency & disasters. In these conditions their advantages include global coverage, anti-disaster capability, immediate & flexible network configuration, and satellite can act as a backup link for terrestrial link [1],[2],[3],[4]. Satellites have the potential to bridge significant digital gaps in all worldwide connectivity issues.

Recent satellite research shows that there are many issues to be solved; such as internetworking with other access technologies such as LAN & Wi-Max [5],[6], enhanced QoS provisioning over multi-segment networks (including satellites), security and On-Board Processing satellites usage for challenging applications over satellites.

Based on altitude, satellites are categorized into three categorized: Geo stationary Earth Orbit (GEO), Medium Earth Orbit (MEO) and Low Earth Orbit (LEO). MEO and LEO satellites have shorter round trip time and GEO satellite have long round trip time. Terrestrial networks can be connected to the Internet over satellite networks by deploying satellite interfaces at earth ground station and clients.

The routing issues with satellite link are important when the satellites are in LEO or MEO orbits, which cause a constant and rapid change in the network topology. The existing routing approaches of terrestrial networks cannot be applied directly to the satellite networks due to some inherent feature of satellite links such as latency, high bandwidth delay product and packet loss due to transmission error of links. Also, the existing solutions developed for mobility management of terrestrial networks cannot handle the frequent topological changes of the satellite systems (in case of LEO & MEO).

The rest of the paper is organized as follows: Section II precisely mentions the objectives of the survey paper and how this article is different from the existing survey in the domain of satellite based communication. Then a literature survey point out the related research & survey papers with comments on their missing parameters or components. Section IV presents the survey model of this paper with a lucid explanation of the parameters considered in the survey. Then a thorough survey is presented for the satellite based data communication with comparison and comments on the existing approaches and performance. Finally, the paper is summarized with the open research issues.

II. OBJECTIVE OF SURVEY

A variety of research work has been carried out on satellite based communication and some survey papers are also published. However, either the survey paper has been written almost before couples of years (which have not included the latest developments) or some paper is written, recently with consideration of only one parameter, component or the scenario. Hence, there is a need to write the survey paper in the integrated form, which has the relevance of modern and novel research approaches with the reflection of already documented survey paper and their limitations. Thus, our major objective is to summarize the techniques & approaches for the satellite based data communication in broad and integrated form and to keep the research community updated in the domain.

The demand of emerging multimedia rich applications needs a communication infrastructure which supports very high bandwidth and QoS guarantees. For emerging applications the existing TCP/IP service model is not suitable and results in the poor end user experience. End user QoS require the efficient cooperation from all the layers of the TCP/IP stack. Thus, one of the objectives of the paper is to fully explore the QoS for satellite based networks and to highlight the related research works.

Interplanetary data communication is going to be the upcoming area in the design, development and deployment of space communication technologies. Hence, another objective of this survey paper is to point out the related research works in the area of interplanetary communication and its research challenges. We have also explored the research works related to the mobility management (in case of LEO & MEO satellites), explicit load balancing and packet reordering issues for the satellite based data communication. Above all, we have also reflected and pointed out the already documented survey papers in the area of satellite based data communication.

III. LITERATURE SURVEY

S.Kota et al. presents a survey of end-to-end QoS and parameters at each layer for satellite IP networks [1]. Akyildiz et al. presents a survey of the interplanetary networks architectures, algorithms and protocols [2]. Ruhai Wang et al. summarize protocols and mechanisms for reliable data transport in space Internet [3]. Reference [4] provides a detailed comparison of the handoff and mobility management schemes for satellite based data communication.

Reference [1] presents the survey with QoS parameter and [2] presents the detailed survey on interplanetary Internet, But this paper were documented in 2003 and so these papers have not covered the recent developments in the area of satellite based data communication. Reference [3] surveys protocols & mechanisms for space internet while [4] represent summary of the mobility management mechanisms for satellite-based networking. But, each of this paper concentrated on the one aspect of the satellite based communication only. In literature so many other papers are also documented with reference to satellite based communication, but with only consideration of one component of the research challenge. Thus, the aim of our survey article is to focus on the recent developments and to present the research progress of technologies in the area of satellite based data communication in integrated form.

IV. SURVEY MODEL

We have selected the criteria based on their impact on end user applications.

A. Quality of Service

QoS is the ability of a network element to provide guarantees that its minimum service level requirements can be fulfilled. QoS required to manage data rate, according to the application expectations and communication parameter requirements. QoS is an important issue to be addressed. Delay, Jitter, Bandwidth-Delay Product, Packet loss and Reliability are important QoS parameters. At each layer, using efficient technologies and counteracting any factors responsible for performance degradation achieve the user performance requirements. However, a robust solution for end-to-end QoS objectives, including security needs extensive research.

B. Interplanetary Networks & Internet

The Interplanetary Internet is expected to facilitate communication infrastructure for scientific and environmental data communication and navigation services [8]. Application of Interplanetary Internet is scientific data acquisition and delivery as described in [9]. Typical applications are Time-Insensitive Scientific Data Delivery, Time-Sensitive Scientific Data Delivery, Mission Status Telemetry, Command and Control.

C. Mobility management in Satellite Networks

NGEO satellites have less round trip time and low power requirement compared to GEO satellites. Rotation of NGEO satellites around the earth results in frequent disconnection with earth station, which needs to have mobility management at the IP layer. Because of the wide coverage area and uniform service facility, satellite networks can play an important role as a carrier network. Hence, satellite constellations needs to be treated as the terrestrial networks to facilitate efficient data communication [7],[8],[14],[15],[60],[73],[81],[83]. Mobility management for satellite networks is based on link layer [10], network layer [11] and transport layer [57] to manage end-host and constellation mobility.

D. Explicit Load Balancing & Packet Reordering Issue

Nongeostationary (NGEO) satellite communication systems are observed as an inseparable part of the modern generation communication infrastructure. Due to the uneven distribution of client-sites on earth in satellite footprints, some satellite links are heavily loaded, while others remain unutilized. Such a communication paradigm leads to congestion of the heavily loaded links, which results in buffer overflows and packet drops. In ELB, a congested satellite requests its neighboring satellites to forward a portion of data via alternative paths that do not involve the congested satellite. This feature gives better traffic distribution and reduces the overall packet drops that may occur at the congesting satellite, it raises the packet reordering issue.

V. SURVEY DETAILS

In this section we will compare and point out the existing approaches in the area of satellite based data communication with respect to the parameters mentioned in the previous section.

A. Quality of Service

1) Physical Layer QOS: Emerging applications need to utilize satellite services. There is a concern to apply modern techniques to enhance the data transmission capacity of the satellite transponders. The upcoming technologies are characterized by the way they improve either power performance (Eb/N0) or data moving capacity or both. Other criteria to achieve guaranteed QoS is to have rain attenuation and fade mitigation techniques as detailed in [1], [12], [13]. Existing modulation schemes are QPSK, 8PSK, 16APSK and 32APSK. Efficient modulation scheme helps to achieve high bps.
DVB satellite network standards (DVB-S, DVB-S2/DVB-RCS) have a physical layer which supports different types of modulation techniques. Along with this, the use of enhanced coding technique reduces the probability of burst errors. Moreover, the use of adaptive coding and modulation allows the optimization of satellite network resources with efficient throughput.

There are so many enhanced technologies for terrestrial wireless networks, but it is really interesting to see the compatibility of these technologies into satellite based networks. It is also required to develop the prototype of physical layer for integration of terrestrial wireless and satellite networks.

2) Link layer QOS: Medium access control (MAC) approaches needed to be adjusted to provide required QoS. Several experiments were done on SATNET [16], [17] to test the feasibility of various MAC approaches and performance measurements on satellite networks. Various TDMA based MAC mechanisms have been presented in [18], [19].

MAC protocol needs to be standardized for satellite communication and efficient interactive communication. Performance analysis of different MAC approaches is detailed in [18], [20]–[26], [78]. Dynamic bandwidth allocation algorithms [27]-[30] and cross layer approaches [31] need further research to provide QoS.

3) Network Layer QOS: To provide guarantee for some minimum QoS in satellite networks the following issues required more research:

DiffServ/IntServ: DiffServ & IntServ approaches are used for terrestrial networks to achieve desired QoS. QoS architecture requires to be developed for satellite networks keeping the differences of terrestrial link and satellite link characteristics at the centre of the architecture.

MPLS satellite QoS: It provides guaranteed QoS for terrestrial networks. The application of MPLS traffic engineering approach needs to verify with satellite network architecture for the desired level of QoS. Security issues for satellite networks with multicast feature, encryption mechanisms, tunneling and PEP need through research.

4) Transport Layer QOS: Satellite network architectures that support Internet access, uses TCP/IP stack. The main characteristics of the link that affect the performance of transport protocols for satellite networks are latency, asymmetric data transmission capability and losses due to transmission error of links. Following link characteristics degrade the QoS of transport layer protocols:

Round trip time (RTT): Due to the high altitude of GEO satellite, it takes long time for TCP sender to determine whether or not a packet has been successfully received at the destination. This long rtt affects interactive applications and also the congestion control algorithms performance remains poor.

Bandwidth-delay product: The bandwidth-delay (BDP) product defines the amount of data that has been transmitted but not yet acknowledged at any time to fully utilize the available link capacity. The delay is the RTT and the bandwidth is the capacity of the bottleneck link.

Transmission Errors: satellite channels have a higher bit-error rate (BER) than terrestrial networks. TCP assumes that all packet losses are due to congestion and reduces its cwnd to alleviate the congestion. Hence, packets dropped due to the link characteristics cause, TCP to reduce the size of its sender window, even though these packet losses do not indicates the congestion in the network.

Asymmetric bandwidth: Due to the limited availability of the channels, satellite networks are configured with asymmetric link characteristics. A common configuration is that the uplink has less capacity than the downlink channel. This asymmetry has an impact on TCP performance.

Slow start & congestion avoidance phase of TCP also affect the QoS at transport layer especially for satellite networks. Recent survey articles provide detailed discussions on performance issues of TCP for the satellite link [3], [34]-[38].

The existing TCP enhancements documented in details are initial window [39], delayed acknowledgements [40], TCP vegas [41], TCP SACK [42]. To enhance the performance of TCP for large BDP (e.g. satellite, OFC link) many solutions have been proposed. To enhance the performance of TCP for satellite links, many approaches are extensively studied in [3], [43]–[45]. Enhancement of TCP for large distance communications have been studied and recorded in [1], [3]. Performance enhancement proxies (PEP) [47]-[49], Quick-start TCP [50], High-speed TCP [50], TCP peach [51], TCP Westwood [52], Explicit control protocol (XCP) [53], Satellite transport protocol (STP) [44], TCP Noordwijk [75] are some of the techniques to improvise the performance of TCP in satellite based network.

In [76], [78] authors have identified that there is an urgent need to find the best congestion control mechanism for space Internet. The study reveals that the traffic shaping mechanism of a rate-based transmission mechanism is more effective than the window-based mechanisms in error-prone space environments with a long link delay. Reference [85] conducts a comparative investigation of existing data transport acknowledgment mechanisms for possible adoption in the unreliable environment of space or a similarly stressed communication environment. Reference [78] describes the framework of the performance of TCP sources and MAC layer available in literature. Reference [79] involves the configuration of TCP-Performance Enhancing Proxy agents at the transport layer and the scheduling algorithm controlling the resource allocation at the Medium Access Control (MAC) layer.

Table I provides summary of the QoS for satellite based data communication at different layers of the protocol stack. Table II give a brief overview of the TCP enhancements to achieve desired QoS for satellite based data communication. All existing mechanisms to achieve desired QoS at transport layer have solved one or more issues but not the all, the same is also described in [3]. So there is a need to develop single and robust solution to achieve desired QoS at transport layer.

B. Interplanetary Networks & Internet

Transport layer functionalities are critical for both reliable transmission of data and the timely delivery of multimedia contents in the interplanetary Internet. Reference [2] summarizes the research trends in this direction and describes the solution for the reliable transmission of data and multimedia contents. In [74] the definition of network architecture suitable to support both communication and navigation services for future space mission is considered. Author request the reader to refer [74] for detailed explanation of improved transmission strategy and its performance measures.

In [65] authors dealt with development towards an Interplanetary Internet (IPN) & research challenges. Interplanetary network architecture is shown in Figure 1 and key research areas have been defined and discussed in [65]. Enhancements required at different layer of protocol stack for interplanetary internet are summarized in Table III.

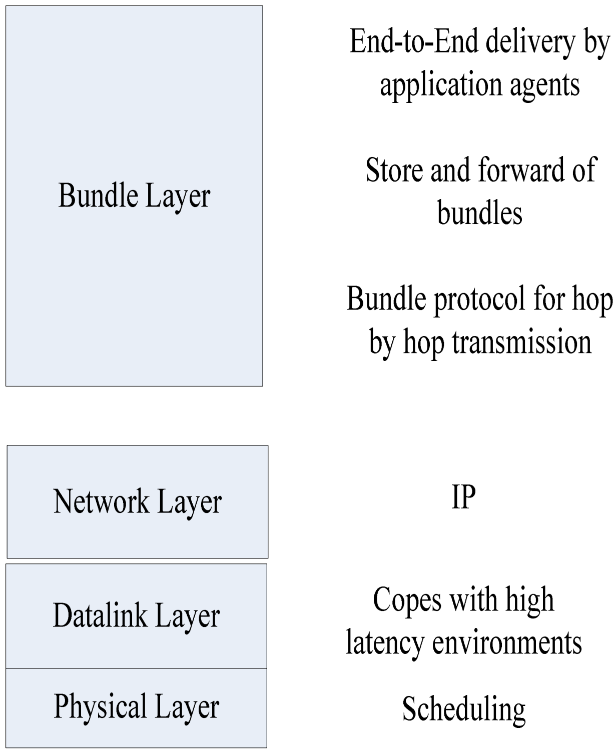

Figure 1 General Architecture of Interplanetary Internet

C. Mobility Management

The performance of data link layer handover mechanisms can be evaluated using following QoS criteria:

– call blocking probability (Pb)
– forced termination probability (Pf)

In different handover schemes, there is a tradeoff between Pb and Pf [10]. Reference [80] discusses the categories and comparison of spot beam handover and network layer handover approaches. The Internet Engineering Task Force (IETF) designed Mobile IP (MIP) [55] and Mobile IP version-6 (MIPv6) [56] to manage host mobility in terrestrial networks. An IP diversity-based host mobility scheme, called SIGMA, has been developed to improve handover performance [57]. These protocols are adjusted for the satellite link [58], [59].

When all hosts of local area network move together, network mobility (NEMO) [60] can be used to manage the movement of the hosts. To improve the performance of NEMO, an IP diversity-based network mobility scheme called SINEMO has been designed [61]. Reference [82] pinpoints the impact of mobility in a satellite system with key network features like QoS, multicast and the specific issue of TCP acceleration with PEPs. It is really interesting to realize the research challenges identified in [4]. Comparison of existing mobility management scheme is summarized in Table IV.

TABLE I. QoS PARAMETERS AND THEIR MECHANISMS AT DIFFERENT LAYERS

Layer	QoS parameters	Mechanism
Physical layer	Increased bps/Hz	Modulation techniques: QPSK, 8PSK, 16APSK, 32APSK
	BER (reduces Eb/N0)	Advanced Coding technique (e.g. Turbo coding)
	Efficient Throughput with conserving most valuable resource of the satellite communication system (constant data rate with varying channel conditions)	Adaptive coding: Automated sensing of the channel condition & degrading or improving the link condition to control the coding rate.
	Attenuation due to rain	Uplink & Downlink power control
Data link layer (i.e. MAC layer)	Delay, Throughput	Multiple Access Schemes (e.g. DAMA)
	Guaranteed bandwidth	On demand bandwidth allocation algorithms
	Configuration adaptability in terms of bandwidth allocation (must be supported by upper layer)	Cross layer approach
	Constant bandwidth with fading (fading due to adverse atmospheric events)	Dynamic bandwidth allocation algorithms with varying channel conditions.
Network Layer	Guaranteed & fixed data rate, Packet delay & loss	IntServ (Integrated Services)
	Scalability, Traffic Shaping	DiffServ (Differentiated Services), MPLS
	IPSec	End-to-end encryption protocols, overhead optimization, PEP
Transport Layer	Delay, Throughput	TCP enhancements, some proprietary solutions
Application Layer	Throughput	Varies from application to application

D. Explicit Load Balancing & Packet Reordering Issue

References [67], [68] propose an "Explicit Load Balancing" (ELB) scheme. ELB has given the concept of load balancing on different links via multipath routing strategies. This multipath routing strategy leads to the packet reordering issue. In connection oriented protocols, packets reordering issue results in to reduction of the data transmission rate, which is not required at all. A mechanism to solve this issue is proposed in the design of ELB itself. To cope with packet reordering issue in ELB, [69] suggest some minor modifications to the TCP implementation at the receiver side to enable receivers to judge the actual reason beneath the out of order reception of packets. It would be interesting to implement ELB & packet-reordering solution as part of all enhanced transport layer solution for satellite-based networking and measure the performance on real test bed.

TABLE II. TRANSPORT LAYER (TCP) ENHANCEMENTS FOR REQUIRED QOS

Solution Categories	Name of the protocol	Issues (problems) Solved	Issues not solved or drawback
Modifications required in TCP protocols only	SCTP	Long RTT, High BER, bandwidth asymmetry and distinction between congestion & transmission error.	Compression of header on error prone channel
	STP	High RTT, High BER, bandwidth asymmetry	Distinction between congestion & transmission error.
	XSTP	Long RTT, High BER, bandwidth asymmetry and distinction between congestion & transmission error.	High overhead
	TCP Peach	Long RTT, High BER	Bandwidth asymmetry and distinction between congestion & transmission error.
	TCPW	High BER	Long RTT, bandwidth asymmetry and distinction between congestion & transmission error.
	TCP- Noordwijk	Long RTT, High BER, bandwidth asymmetry and distinction between congestion & transmission error, signal outages	Need to evaluate in real test bed
Modifications required in TCP and network infrastructure also	XCP	Long RTT	High BER, bandwidth asymmetry
	P-XCP	Long RTT, High BER	Bandwidth asymmetry
	REFWA	Efficient link utilization & fairness	High BER, long RTT, bandwidth asymmetry, distinction between congestion & transmission error
	REFWA plus	Efficient link utilization & fairness, distinction between congestion & transmission error	Need to evaluate
Modification required only at the two end of the satellite link	Performance Enhancing proxies	Long RTT, High BER, bandwidth asymmetry and distinction between congestion & transmission error.	Break the end-to-end semantics and use of IPSec requires considerable research

TABLE III. ENHANCEMENTS FOR THE INTERPLANETARY NETWORKS

Layer	Issue/Enhancement required	Technique/Mechanism
Physical layer	High transmission efficiency over long haul communication links so communication sessions must be scheduled.	Ahead pointing
	Antenna pointing accuracy is another issue	Need considerable research
Data link layer (i.e. MAC layer)	Multiple access schemes with highly complex scenarios	Need to improve CCSDS proximity-1 protocol for complex scenario
Network Layer	Highly mobile & evolving scenarios/topology	Need to tune network layer protocols with mobility Terrestrial routing protocols need to be investigated and if required then need to update
Transport Layer	Lot of research work for interplanetary networks has been done	For successful deployment it is desirable to agree on one solution or the standard

TABLE IV. COMPARISON OF MOBILITY MANAGEMENT SCHEMES

Layer	Mobility management scheme	Advantages	Disadvantages
Network Layer	Mobile IP	Efficient routing, predictable movement of satellite can be utilized to improvise the performance compare to terrestrial mobile networks.	Overhead due to the standard procedure of mobile-ip, triangular routing and changes in infrastructure is required
	Mobile IP version 6	Route optimization which remove the triangular routing	Changes in infrastructure is required
	Fast Mobile IP version 6	Less handover latency compare to MIP & MIPv6	Need to evaluate for satellite networks
	Hierarchical Mobile IP version 6	Less signaling overhead & efficient in routing	Need to evaluate for satellite networks
	NEMO Basic Support Protocol	Extension of MIPv6 and can manage network mobility	Inefficient routing & changes in infrastructure is required
Transport layer	SIGMA	Handover latency is very low, very efficient in routing, changes in network infrastructure is not required, no extra overhead	
	SINEMO	It can handle network mobility	Still network mobility issue need considerable research work

VI. CONCLUSION

This section describes the open research goals in the area of satellite based data communication.

In order to assure some minimum QoS guarantees, significant improvement is required in the areas of efficient modulation technique, advancement in coding approaches, on demand bandwidth and traffic engineering approaches for upcoming applications. In satellite based networks, research on return channel access protocols, QoS based architecture and interaction with cellular technologies is required. In literature, research results have been reported for TCP improvements and optimization of TCP performance for satellite links. These results need to focus on the modern and emerging applications with QoS model at the centre. In order to standardize the specific enhancement analytical and simulation results are not sufficient. These results need to be complimented by testbed experiments and detailed analysis.

Power generation is via natural resources and constraint in computational resources at the planetary distant communication nodes and other entities, the cross-layer optimization is the need of an hour and an important direction to move forward. The cross-layer approaches for transport layer protocols must be researched to optimize the resource utilization in the extreme networking environment such as interplanetary communication, satellite based data communication and Internet access via satellite link.

In [67], it concludes that the actual enhancements that the ELB scheme can indeed bring to differentiated services architectures over NGEO satellite system are interesting research areas. Reference [4] summarize that experimental results need to evaluate for majority of the DTN protocols. Network mobility for satellites with on-board LAN is a research issue, which need more focus [4]. Integrating QoS with mobility management in space segment networks can be an interesting research area.

In most of the research work, it is assumed that some minimum numbers of satellites are needed for global coverage. Thus, the overlapping coverage areas of the nearby satellites do not explored for the satellite coverage. In highly populated areas, for efficient communication resource management, overlapping area between the nearby satellites can be increased. Changing entire satellite constellation, in such a heavily populated area, need better resource and handover management with further investigation [80]. For an efficient data transport in space Internet an efficient acknowledgement scheme is mandatory. SNACK is recently proposed acknowledgement mechanism so an experimental comparison between SNACK and NAK mechanisms should be conducted to verify the predicted performance advantage of SNACK. Impact of SNACK on the different flow and congestion control mechanisms proposed for TCP should be studied, especially for a large BDP environment like space. It is interesting to develop inter-satellite communication architecture (i.e. GEO, MEO, LEO) and to develop multi-hop routing protocols to make satellite data communication very efficient and robust. Here, existing Mobile ad-hoc networks routing protocols can be a guideline to move in this direction.

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