A Novel Dynamic Bandwidth Allocation Model for Energy Efficient Multi-beam STICS Networks

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Abstract—

Dynamic bandwidth allocation, keeping in view of energy efficiency is the utmost solutions to achieve flexible and efficient satellite based cellular networks. This would be helpful for communicating with anywhere and with anyone with global coverage. In this research article it is proposed that the assignment of bandwidth must be dynamic for this energy efficient mobile-satellite integrated system since user capacity demand is going to double by 2020. The model for such assignment is chosen in terms of obtaining energy efficiency thereby conducting measurement of interference. For this the quality of service on the basis of link control of threshold for a spectrum must be known. A pattern with frequency reuse ratio of 1 and 3 is selected consecutively keeping the fixed access satellites constant for the evaluation of energy efficient STICS systems. If the quality of link obtained from proposed model is maintained greater than blocking rate the frequency reuse would be unity. But in ideal case we can say that bandwidth requirement for quite large users can be sustained by implementing the model described in this paper

Keywords— **STICS, MSS, Dynamic bandwidth, frequency reuse, beam-forming, blocking rate, traffic ratio.**

I. INTRODUCTION

Satellite & Terrestrial Integrated mobile Communication System (STICS) Networks can provide link towards integration of mobile phones in terrestrial region and satellite in outer space. Low level radiations are generated using digital technology over a wide range of frequencies.[2] Using digital technology there is great increment in number of personal device assistants using cellular technology integrated with low orbit satellite networks. Bandwidth requirements from the above devices are expected to increase several times since beyond observatory, there is no control over evolution of future generation terrestrial radio devices. The range of frequencies that mobile broadband device occupy is preferably below 6 GHz but in spectrum this may appear much higher. For example the band of frequency by vehicular radars at starting point is 71-81-GHz. These radars are already found in automobile industry. For these newer model vehicles, more advanced algorithms would be implemented. This would employ energy efficient dynamic bandwidth allocation schemes for providing services to large users and must be developed by 2020.

The services stations of satellite communication can be categorized as Mobile Satellite Stations (MSS) and Fixed Satellite Stations (FSS). The future Global satellite communication systems are focused or represented by MSS. The phone services based on satellite are suffering because of competition from cellular technology and providing near global coverage in a reliable and in a affordable manner. Moreover there is a requirement for the existence of line of sight (LOS) from the services of satellite which is very difficult to guarantee in urban areas because of presence of high building and almost impossible in case of indoor propagation. Spot beam from satellite can be considered as a measure of multi-beam satellite cell using beam-forming terminology. The size range for spot beam varies from narrower region in the order of 100 kilometres to larger global regions of about one-third of the earth's surface.

TABLE I

SATELLITE CONSTELLATIONS USED FOR S.T.I.C.S SERVICES IN A DECADE

Year of Launch	Satellite Constellations	Orbit Type	Issuer	Spectrum Band
2004	SKYTERRA	GEO	FCC	L-band
2006	GLOBALSTAR	LEO	FCC	L-band
2009	INMARSAT	GEO	EC	S-band
2009	ICO	GEO	FCC	S-band
2009	SOLARIS	GEO	EC	S-band
2010	TERRESTAR	GEO	FCC	S-band
2015	IRIDIUM-Next	LEO	FCC	Ka-band

The satellites must integrate the cellular signals and must serve for the required purpose [4]. Therefore in the case of natural disasters or special event for example, it is required for satellite systems to allocate the frequency resources to a specific area as much as possible. The major satellite constellations that can solve bandwidth requirement and are identified as MSS are listed in Table I.

II. PROPOSED MODEL FOR S.T.I.C.S NETWORK

A. Merits of terrestrial mobile cellular networks over MSS

Spectrally Efficient: Spot beam in satellite is used to perform frequency reuse for spectral efficiency which are limited.

Wider Coverage: As the entire surface of planet is covered by satellite spot beam the coverage area is quite large.[8]

Disaster tolerant: Earthquakes and hurricanes fail all ground based communication due to damage in infrastructure but satellite can provide communication in such cases.

Less Costly: In urban areas cellular networks provide low cost for high density population. Typically 0.15 to 2 per minute for a voce call from satellite phone is served.

More Coverage for denser regions: Line of Sight (LOS) condition is not needed for ground based communication in urban and dense urban areas and hence providing better communication contradicting to MSS**.**

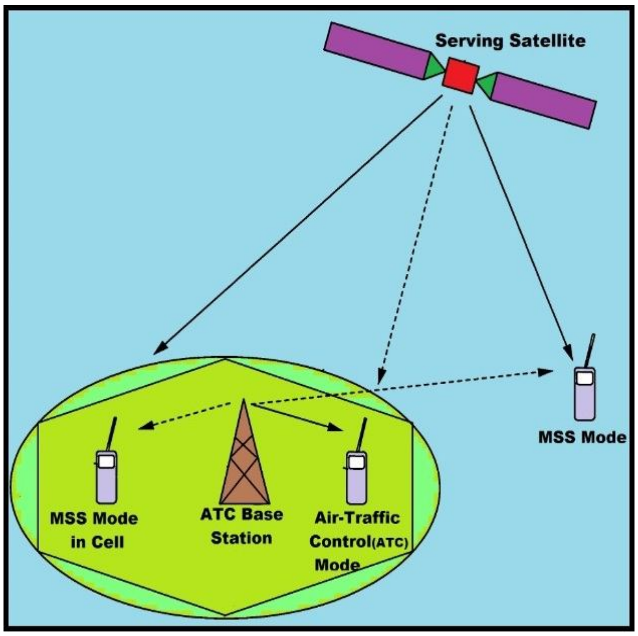

Fig. 1 MSS/ATC satellite-cellular network.

For the advantage of both systems there is a need of a hybrid network consisting of both satellite and ground component and must complement each other. This ground component in is called as air-traffic control (ATC). The complementary of ATC is mobile station serving mode which is the ground component. This hybrid network is referred as MSS/ATC and is highlighted in figure 1.

B. Integration of cellular networks with Multi-beam STICS

The main differences between satellite and cellular cells are listed below:

Size of Cell: Range for cellular cell varies home cell to macro cell (around 30km) but for satellite range is from 100 to 1000 km according to satellite altitude.

User Mobility: User's mobility necessitates handover across cellular cells i.e. from one base station to another base station. Since cells are not geographically fixed for non-stationary satellite as they follow the movement of satellite which is with respect to a fixed point on ground, hence handover is necessary for fixed users from one satellite to other satellite.

Current MSSs include satellite which is low power transmitter with a small size of antenna on the other hand large antenna with high power device is used by user. However for future satellite huge antennas are used which are for high transmission power alternatively small size and reasonable power consumption for user terminals. For small-sized handheld device High link margin is required in MSS but this has the disadvantage in limiting MSS capacity opposed to FSS from 10,000 to about 3000 to 4000.[5]

The system performance of MSS in satellite can also be described from the amount of onboard processing (OBP).Since GEOs (Geosynchronous Earth Orbit) satellites are acting as relays between ground points and hence serving as bent pipes. Direct communication between satellites is possible through OBP but the satellites should have same constellation. Hence inter-satellite links (ISL) are enabled for faster call routing. This process significantly decrease delay in voice communication return-link based on satellite.

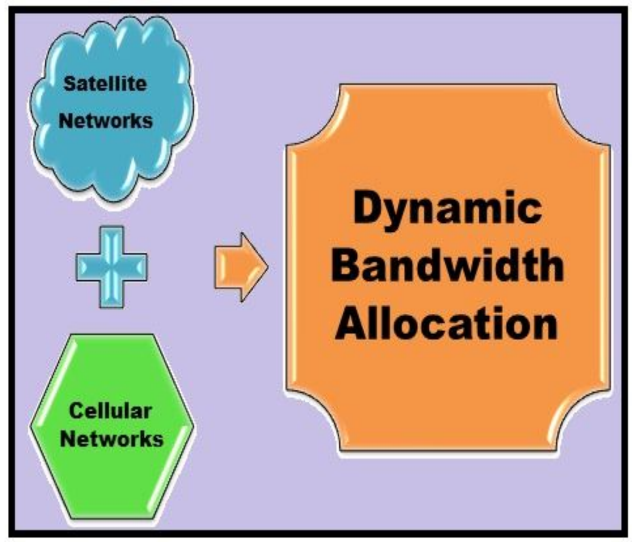

Fig. 2 Block-diagram showing integration of satellite-cellular networks

C. Beamforming in Multi-beam STICS Networks

Beamforming is defined as the choice of antenna irrespective of size, shape and aperture either for transmission or reception which will result in certain beam shape.[1]

Antenna gain (A) is determined from beam shape, hence to maximize received power and increase energy efficiency beam shape must be controlled in certain direction.

One technique used for beam shaping is called digital beam forming which is a signal processing technique that combines an array of non-directional antennal element to directional antenna. The expression for antenna gain A(∅) is given by

$$A(\emptyset) = \begin{cases} \cos^{\theta_H}(\emptyset) & ,\text{for } |\emptyset| \le \emptyset_\alpha \\ \alpha & ,\text{for } |\emptyset| > \emptyset_\alpha \end{cases}$$

Where, θ_H, ∅, α are half-power beam-width, antenna pointing angle, attenuation factor respectively and

$$\alpha_{max} = \cos^{\theta_H}(\emptyset)$$

$$\theta_H = \log_2\left[\cos\left(\frac{\phi_H}{2}\right)\right]$$

When θ_H tends to zero, 'α' is set to -20 dB for performance evaluation. The direction of resulting beam can be controlled by beam steering by feeding the element of antenna of equal gain and different phases. The main advantage of digital beam forming is that it has it is flexible. Without changing hardware adaptively beam shape is changed with its direction, hence providing dynamic area coverage by spot beams according to traffic demand in network. For a long time central group controller (CGC) has been used in broadcasting of satellite network and is a simple repeater or gap filter as it fills the holes in satellite coverage area. Same frequency can be used by CGC as segment of satellite or certain frequency to receive signal from satellite. [13]

D. Energy Efficiency in Dynamic Bandwidth Allocation

The concept of frequency reuse can be used for satellite non-adjacent cells but it will be limited due to formation of a large number of spot beams impractically. This is shown in figure 3, where the scenario of marked points in a cell is chosen in our model for allocating bandwidth dynamically.

A switching office is employed for a satellite communication network system by a mobile satellite system having a satellite antenna for the transmission and reception of satellite messages via satellite to and from an earth station mobile. For transmission and reception of a satellite message, a central controller from the earth station mobile is used by connecting communication switching office to the satellite interface system. A network operations centre (NOC) of a mobile satellite system conducts the administrative functions associated with satellite management network system and also controls the resources of satellite management network system. NCC is the supporting system for communications circuits between satellite switching office and mobile communication system. The available circuits in circuit pools are managed by Central Group Controller (CGC) in NCC. CGC include components that are responsible for management of resources during clear down and call setup, management of database, traffic statistics, and management of call record and performance verification testing periodically.[15]

Total request of all ground terminals are computed by NCC then NCC computes average bandwidth. If 'b_k' is the bandwidth requirement of the n^{th} arrived request, and N is the number of ground terminals. The average bandwidth requirement is given by

$$B_{avg} = \frac{\sum_{k=1}^{N} b_i}{N}$$

For the proposed model NCC can assign average bandwidth B_{avg} to all requested ground terminal which is analogous to operation of an Omni-directional antenna for which is frequently incorporated for increasing cell capacity of mobile networks in a cluster . Therefore, it is argued that this system would be energy efficient.

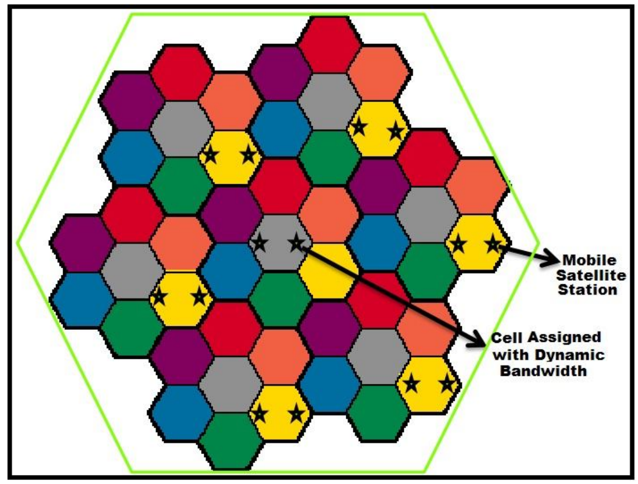

Fig. 3 A sample line graph using colors which contrast well both on screen and on a black-and-white hardcopy

E. Algorithm Dynamic Bandwidth Allocation.

One important thing here is that satellite base station (BS) measures the interference from the mobile satellite station (MSS). But the contrary of this is not possible i.e MSS cannot measure the interference from satellite base station in reverse channel. At this stage MMS is commanded by BS for the report of interference measurement of forward channel BS to MSS which is illustrated in figure 4.[5]

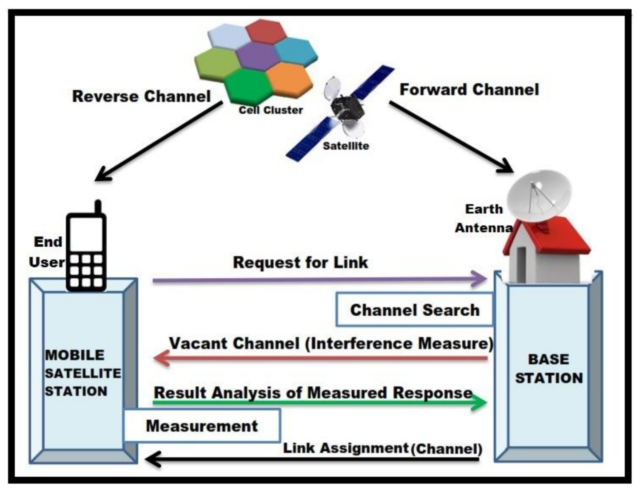

Fig. 4 Dynamic bandwidth allocation process for a channel in a cell-cluster for STICS network.

Figure 4 show that bandwidth is assigned dynamically based on channel vacancy and interference measurement. A measure of determining the observed interference is the signal to noise ratio, denoted as S/N. Since the algorithm employed for this technique follows a routine to monitor allocation of bandwidth on the basis of link quality threshold of applied signal and goes on step by step, an increment of noise 'N' becomes necessary due to addition of interference 'I'. Thus the term 'S/(N+I)' will be used in the context of algorithm used. As shown in figure 3-4, when a bandwidth is demanded to satellite BS by MSS, BS measures interference for the unused bandwidth in satellite where MSS exist and BS assigns the bandwidth with minimum interference or highest 'S/(N+I)' among the unused bandwidth. After getting bandwidth request from MSS or terrestrial network, satellite BS starts searching for vacant bandwidth and among vacant bandwidth which is a measure of the quality of return link provided by the STICS network. In case if vacant bandwidth is available, MSS selects the bandwidth number with least interference i.e. high 'S/(N+I)' and reports back to SBS after measuring the interference at each vacant bandwidth.[4]

Algorithm1: Dynamic Bandwidth Allocation for Energy Efficient Multi-beam STICS Networks.

1. System Calls for Assigning Bandwidth in Channel
2. IF (Channel Vacant for assignment) then
3. Measure ICI, I(n) in n^{th} channel.
4. Determine S/(N+I) with $I_{min.} > I_T$
5. Assign Dynamic Bandwidth in Channel n
6. ELSE
7. Terminate the Call
8. END IF
9. System Call Ends
10. GOTO '1' for next assignment.
11. END.

The assignment algorithm can be described above. The step 1, 2 call for routine assignment, checking the status of vacancy. In step 3 the inter-cluster interference (ICI) is measured as a function of channel (n). Step 4 checks if the minimum interference incurred I_{min} is greater than the threshold level set by the system I_T. If step 4 is true then the allocation of dynamic bandwidth for the STICS network is accomplished, otherwise the process is terminated. This process is repeated for assigning bandwidths for both low load and high load slots It must be noted that here the quality of link of assigned bandwidth is lower than the required (S/N+I) for heavy traffic and for small frequency reuse factor. When predetermined threshold will be greater than (S/N+I) of the bandwidth, for this case it is better to drop the call. Algorithm 1 shows assignment procedure for the dynamic bandwidth assignment scheme. At last satellite bandwidths of best quality i.e. largest (S/N+I) among vacant bandwidth is allocated to MSS by satellite BS for 'n' numbers of both reverse and forward channels.Hence different time slots of NCC must transmit the required data with same angular direction. When bandwidth less than B_{avg} are requested by some terminal, than NCC assigns the requested bandwidth to them and allocate average bandwidth to all other terminal that request more bandwidth than available. If some of bandwidth is not allocated but all requests are satisfied then computation of free resource will be done and equally assign to all terminals. This process continues till the end of all bandwidth allocation

III. PERFORMANCE EVALUATION

The analysis of performance of the discussed system is done by network simulator-2 (ns2) with model for satellite networks [16]. For dynamic bandwidth assignment on the basis of proposed algorithm, noise with interference measurement must be controlled keeping threshold link quality constant. Since control for multi-beam STICS networks is done some arbitrary data needs to given to the system that best approximates the dynamic bandwidth allocation. Data inputs to modeled systems given are listed below:-

(1) STICS cell clusters = 5
(2) Total Cells = 5×7 = 35
(3) Satellite Stations = 100
(4) Bandwidth per channel = 500 kHz,
(5) Number of channels = 100
(6) Traffic Ratio = 1/1, 1/2, 1/10
(7) Reuse Factor = 1, 3
(8) S/N+I = 20 dB

Major evaluation parameters are listed above. A general traffic model probabilistic, where a call occurs at random and its holding time is constant. Traffic ratio is the ratio of the traffic of each cell divided by that of the cell of interest.

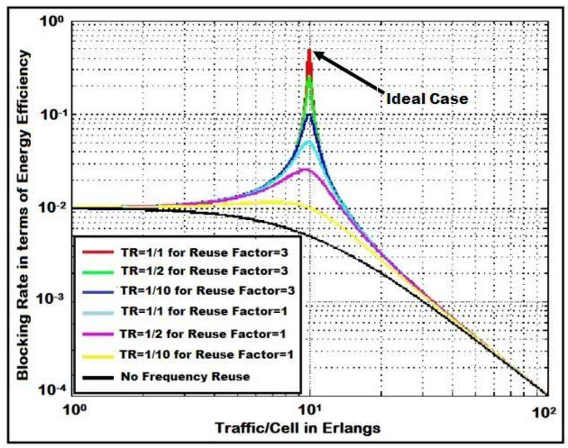

Fig. 7 Analysis of blocking rate plotted across traffics per cell for various traffic ratio (TR) and frequency reuse factor

For all of 35 satellite cells the allocation of bandwidth is on uniform distribution request. For a particular cell of interest, the traffic ratios of 1/1, 1/2, 1/10 are given input with reuse factors 3 and 1 respectively. The blocking rate for seven such combinations was obtained as shown in figure 7. The ideal case is when traffic ratio is 1/1 with reuse factor 3. This does not occur practically since there is always some traffic. Blocking rate in terms energy efficiency goes on increasing 10 times in the plot which is logarithmic in nature. larger traffic occurs at the cell of interest. Out of 100 channels 70 were used for reuse factor 3 and 30 channels are used for reuse factor 1. The bandwidth of each channel is taken to be 500 KHz. Clearly the total bandwidth available dynamically at any time is 100 × 500 kHz = 50 MHz. [15]

Next this a novel dynamic bandwidth allocation scheme which is proposed for STICS network is compared with min-max fair scheme [5] using directional antennas designed in satellite network. This comparison for high load and low load bandwidth slots are plotted in figure 8 and 9 respectively. It is found that the proposed scheme is maximum energy efficient when less number of bandwidth slots are assigned. [10]

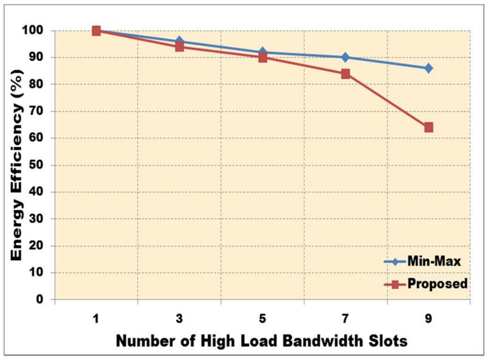

Fig. 8 Study of energy efficiency versus high load bandwidth slots

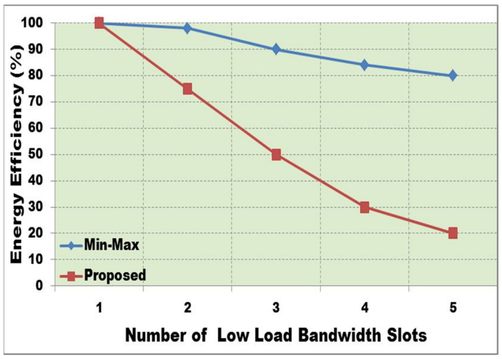

Fig. 9 Study of energy efficiency versus low load bandwidth slots

Figure 8 shows the plot of energy efficiency versus high load bandwidth slots considering 80 satellite stations for allocating high load bandwidth with 10 available slots. 20 satellite stations were used for low load bandwidth slot allocation with 5 available slots as shown in figure 9.

IV. CONCLUDING REMARKS

The dynamic bandwidth allocation method proposed in this research paper can be beneficial for increasing the bandwidth provided by conventional service providers. The results from the performance evaluation on the basis of frequency reuse adapted in communication channels suggest that for a satellite cellular coverage, an increase in energy efficiency is obtained. This can further lead to improvement in cellular capacity for larger inter-cells. The evaluation results obtained by comparing figures 8 and 9 reveal that the proposed dynamic bandwidth allocation scheme is best suited for a highly loaded system that provides maximum efficiency in terms of energy efficiency. The figures in the sections of performance evaluation have provided the optimum results for this dynamic bandwidth allocation model. This model would be suitable for future deployments since consumer demands for continuous wireless services are increasing day-by-day.

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