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RESEARCH ARTICLE

SATELLITE BANDWIDTH ALLOCATION FOR SATELLITE ROUTED SENSOR NETWORKS

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Abstract – Next Generation Satellite Routed Sensor Systems is expected to provide disaster detection system with high real time performance. By using Satellite Networks SRSS realizes data collection from multiple sensor terminals deployed in a wide area. However an efficient access control scheme is needed to achieve multiple access from numerous sensor terminals to the satellite with its limited bandwidth. In order to efficiently resolve these problems we propose a new scheme which utilizes a divide and conquer approach for efficient bandwidth allocation. Numerical results demonstrate the effectiveness of proposal.

I. INTRODUCTION

Designing disaster detection systems by using wireless sensor networks has attracted much attention. It is needed to establish a large scale system to detect disaster at an early stage. In order to collect data early from wide areas Satellite Routed Sensor System is expected as Next Generation System. In Satellite Routed Sensor Systems, each sensor terminal sends data of disaster information such as tsunami, earthquake, volcano to satellite when they detect emergence of disaster. Satellite receives the data from the sensor terminals and sends them to ground stations, which deliver this information to wherever necessary. The system also evacuation and disaster prevention information.

Fixed bandwidth assignment schemes such as TDMA can avoid the collisions; bandwidth allocation in such scheme causes long waiting time and wastes the bandwidth if there are numerous sensor terminals. A method to allocate bandwidth efficiently on demand is needed for the system. We propose a new method using both TDMA and searching sensor terminal having request to send in order to allocate bandwidth in minimum time. The efficiency of the system is analysed with some mathematical expressions and numerical results.

II. NETWORK CONFIGURATION AND ACCESS CONTROL SCHEMES FOR SRSS

We assume the Satellite Routed Sensor Systems constructed by a satellite, sensor terminals and ground terminals as a simple SRSS model to validate the efficiency of communication between satellite sensor terminals. The GEO satellite (Geostationary Earth Orbit) is considered. The satellite provides the communication environment by using the multi beam system. The system can efficiently utilize the frequency because sensor terminals deployed on separate areas can use the same frequency range. Since, the satellite can concentrate the transmission power to a narrow area; it becomes possible to increase the transmission capacity. The frequency range is divided into some channels to permit multiple access without interference. New systems whereas a satellite can collect data from numerous sensor terminals will appear in the near future as a next generation system, hundreds or thousands of sensor terminals are supposed to be deployed in a wide area densely to realize the real time disaster detection system. Therefore, satellite needs to communicate with hundreds or thousands of sensor terminals in each channel. The network configuration is as shown in the Fig. 1.

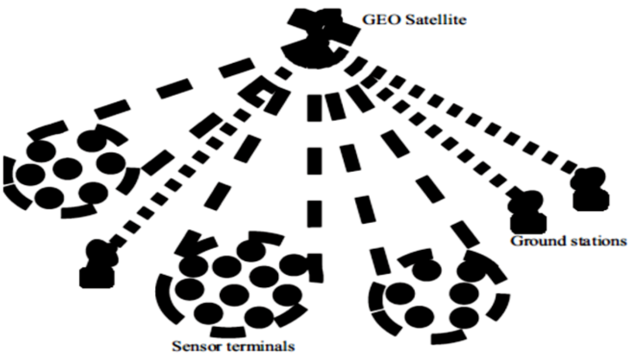


Fig. 1. An example of network configuration of satellite-routed sensor system.

III. EXISTING ACCESS CONTROL SCHEMES AND THEIR SHORTCOMINGS

An appropriate access control scheme is needed to achieve communication between multiple sensor terminals and the satellite without collision at the satellite. For common terrestrial systems CSMA/CD and CSMA/CA are developed. The conventional schemes are classified into two groups as contention based schemes and fixed assignment schemes. Contention based scheme or slotted ALOHA is commonly used in satellite networks. If collisions at the satellite occur due to the data received from multiple sensor terminals waits a random amount of time and sends the data again. The slotted ALOHA achieves higher throughput than ALOHA by controlling the timing of data sending from all sensor terminals. Throughput of real time performance causes the increase in probability that more than one sensor terminal send data to a satellite at the same time.

TDMA is known as a fixed assignment scheme. The sensor terminals are assigned time slots, which are the smallest logical units for bandwidth allocation and send data during the time slots by rotation. Fixed assignments achieve higher performance in limited environments.

Algorithm 1 Proposed bandwidth allocation algorithm

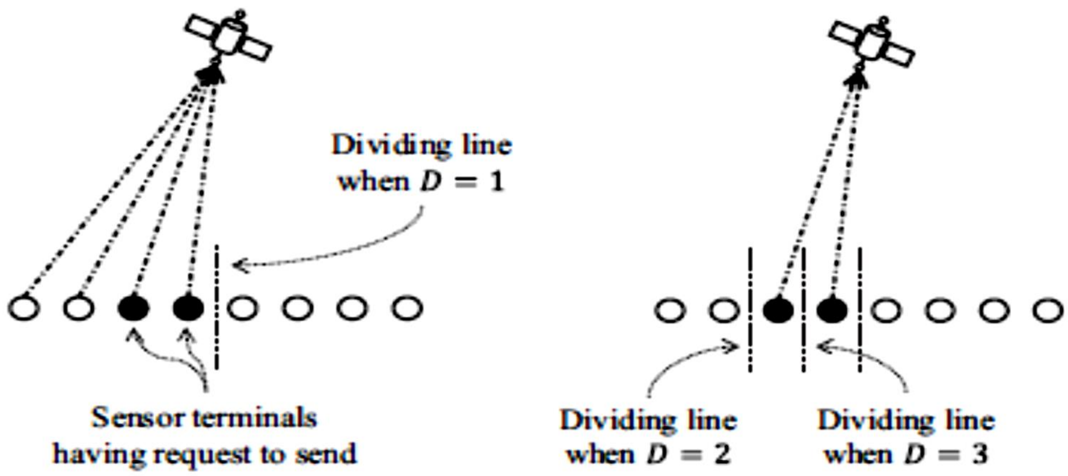
Join all sensor terminals into $G_0(0, N_{\text{sensor}})$
while $D < D_{\text{opt}}$ **do**
  (Start searching phase)
  while $G_i(\alpha, \beta)$ **exist do**
    Send SM to $G_i(\alpha, \beta)$ **in order of** i
    if $N_{\text{RM}} = 0$ **then**
      Remove $G_i(\alpha, \beta)$
    else if $N_{\text{RM}} = 1$ **then**
      Allocate time-slots to the sensor terminal
      Remove $G_i(\alpha, \beta)$
    else if $N_{\text{RM}} \geq 2$ **then**
      Make $G_{i+1}(\alpha, \frac{\alpha+\beta-1}{2})$ **and** $G_{i+2}(\frac{\alpha+\beta+1}{2}, \beta)$
      Remove $G_i(\alpha, \beta)$
      $D{++}$
    end if
  end while
end while
(Start allocating phase)

In this proposed scheme we aim to allocate satellite bandwidth on demand to sensor terminals with minimum operation time in the environment, where numerous sensor terminals share the same channel. The proposed algorithm is shown. In this algorithm we define $G_i(\alpha,\beta)$ as a group of sensor terminals with identification number i. α being the smallest i and β being the largest i. SM is searching message and RM is request message.

Satellite broadcasts SM messages to all sensor terminals to search the sensor, which has request to send data and wait for response from sensor terminals. The above flow is called searching phase and the searching message is called SM. If there is no response from sensor terminals the satellite broadcasts SM's at regular intervals. If sensor terminals have the data they must return the request messages RM's to the satellite. The RM includes identification number of the sensor.

If number of RM's is one, the satellite allocates bandwidth to the sensor terminal. TDMA is supposed as bandwidth allocation methods in this system. The data size of sensor terminals is assumed to be small, because it is enough to the sensor terminals.

If the number of RM's is more than one, the satellite detects collision of RMS's. In this case the satellite divides all sensor terminals into groups according to the identification numbers. Satellite broadcasts SM to one of the groups and repeats the above procedures. If number of RM's is zero, the satellite broadcasts SM to another group. In the proposed scheme satellite allocates time slots to all sensor terminals by using the rotation in the same group, which is called allocating phase. Using these procedures the number of searches can be decreased. There is a trade-off between the amount of time for searching phase and that of allocating phase.



(a) The case when searching phase finishes at the first dividing phase. **(b) The case when searching phase is repeated until the sensor terminals sending RMs are individuated.**

Fig. 2. An example of the case when the searching phase has finished.

Consider, the simple model of Satellite Routed Sensor System constructed by a satellite and eight sensor terminals, which share one channel to communicate with the satellite. In this case it needs to be divided three times to individuate these sensor terminals having data to send. The searching phase repeats until all sensor terminals having data to send are individuated.

We analyse the optimal number of maximum dividing times in our proposed scheme with some mathematical expressions. In this analysis the number of satellites is set to one and number of sensor terminals which share the same channel as $N_{sensors}$. The number of sensor terminals which send RM's at the same time is 2.

We formulate the amount of time for searching phase. It is one cycle that satellite broadcasts SMs and them receives RMs from sensor terminals. One cycle takes time (2.hs)/c, where hs is altitude of satellite and c is the speed of light. Satellite repeats the cycle on several occasions to divide the sensor terminals when data collision occurs due to the multiple RM's. We define maximum number of dividing times as D.

$$T_s(D) = \frac{2hs}{c}.(2.D+1) \qquad (1)$$

$T_a(D) = \frac{N_{sensor}}{2^D}.t$ (2)

Where T_S is searching time and T_a is allocating time for the sensor terminal. Amount of time for allocating phase increases the value of D.

TABLE 1
PARAMETER SETTINGS

Number of satellites	1
Satellite Altitude (hs)	36,000 km
Number of sensors (N_{sensor})	500 – 2,000
Time-slot (t)	50 ms
Speed of Light (c)	3 x 10^8 $_{m/s}$

IV. NUMERICAL ANALYSIS

We verify the change of the operating time in our proposed method with numerical analysis. The correctness of aforementioned mathematical analysis is also presented.

Our supposed network comprises a satellite and numerous sensor terminals on the ground. A GEO satellite is considered as it is suitable to collect data from a wide area on the ground due to high altitude and large coverage. A TDMA based system is considered to be used by the satellite to allocate bandwidth to the sensor terminals. The ideal time for 1000 sensors is set to 50ms in considered system. In order to simplify the verification, we consider the bandwidth allocation in a beam of satellite and a channel in a beam.

Thus, the satellite allocates time slots to hundred's to thousand's of sensor terminals in a channel. We verify the change of expected operating time in our proposed method, which includes the expected required time for searching and allocation phases. We study the relationship between amount of time for searching and allocating phases when the number of dividing times varies from 0 to 4. From Fig.3(a), shows the change of amount of time for searching phase when number of dividing times varies from 0 to 8. It is clearly shown that amount of time for searching phase increases with increase in number of dividing times. This is because the increase of number of dividing times causes increase of number of times for transmitting and receiving messages between satellite and sensor terminals. Fig 3(b) demonstrates the amount of time for allocating phase from Fig 3(b) it is understood that amount of time for allocating phase decreases with the increase of number of dividing time. From Fig.3(a) and 3(b) it is confirmed that amount of time for searching phase increases and amount of time for allocating phase decreases when number of dividing time increases. Thus, the trade-off relationship between the amount of time of searching phase and allocating phase exists. Fig. 3(c) shows amount of time for allocating phase with different time slots. On demand TDMA allocation scheme can provide more efficient bandwidth utilization compared to fixed TDMA schemes.

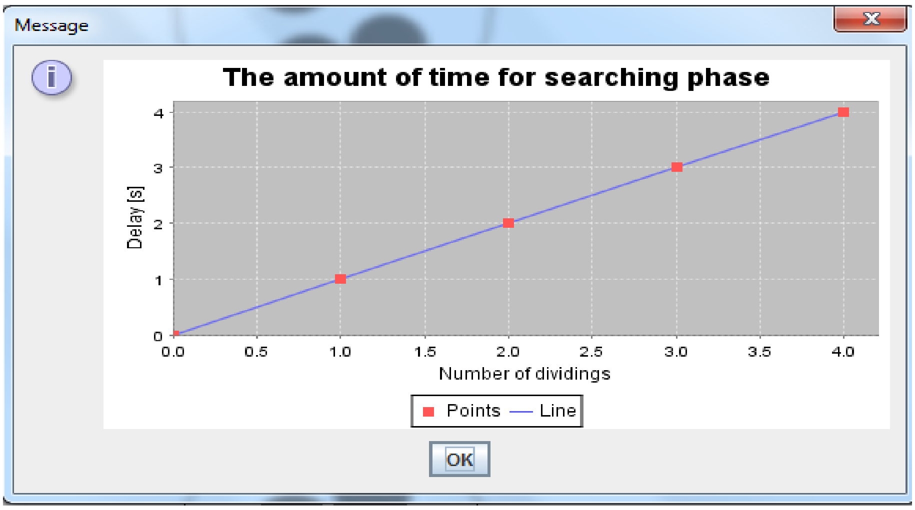


Fig.3(a) The amount of Time for searching phase

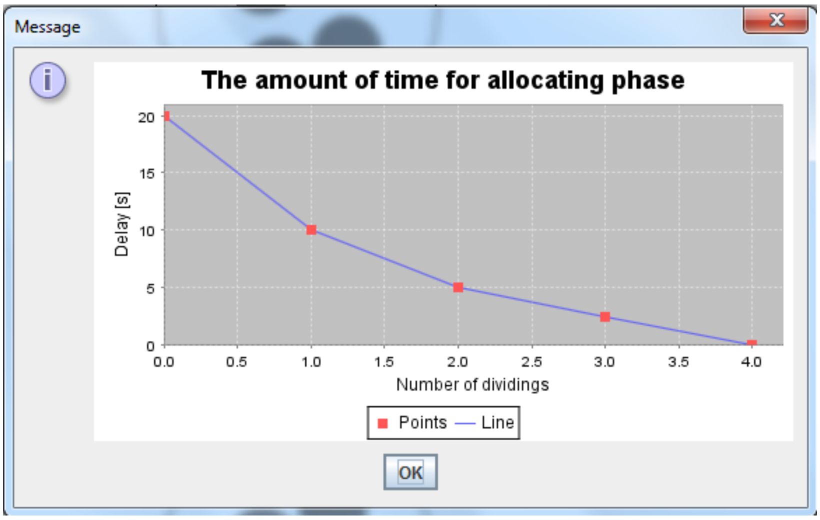


Fig.3(b) The amount of time for allocating phase

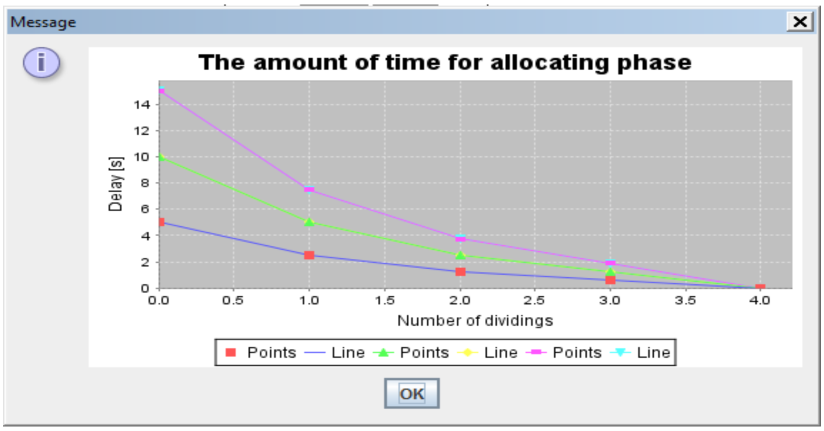


Fig. 3(c) Allocation Time for different time periods

V. Conclusion

In order to realize the disaster detection system all over the world, providing network environment not only to urban areas but also to areas lacking adequate infrastructure (e.g., disaster-affected zones, rural areas, and so on) is essential. In this vein, in this paper, we focused upon using satellites to communicate with many kind of sensors. Since the satellites have many advantages such as wide coverage and they are disaster-resistant, they can be considered as a good candidate to constructs networks facilitating a world-wide sensor networks. Toward this end, we proposed a new method to collect data efficiently from an arbitrary area sensor networks by means of SRSS. In our proposal, the satellite allocates time-slots on-demand to the sensor terminals, which have some data to send, by a divide and conquer-based approach, which consists of two steps, namely the searching and allocation phases. In the searching phase, the satellite finds the sensor terminals having data to send. Moreover, the operating times of the searching and allocation phases are mathematically analyzed, and the total operating time is minimized. By using our proposed method, the satellite collects data from the sensor terminals deployed arbitrarily in a wide area. Thus, in the environment where numerous sensor terminals exist and they generate data at any time, our proposed method makes it possible to collect data from them by avoiding ineffective bandwidth allocation and to decrease the operating time. Therefore, our proposed method realizes global-scaled sensor networks effectively with a significantly high real time performance.

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