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Variable-Slot Split Scheduling Algorithm Technique for Real-Time Industrial Wireless Sensor Networks

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Abstract: Industrial Wireless Sensor Networks (IWSNs) are emerging Wireless Sensor Networks (WSNs) that have received more attention due to their wide industrial applications usages such as condition monitoring, process automation, and environmental sensing. In WSN, wireless devices can exchange information together or between a cluster of wireless devices and the Internet domain through a gateway. Furthermore, sensor technology has made it smooth for the user to discover his surroundings and acquire information, like temperature measurements. This research aims to increase the network resources (such as speed and energy) allocated on-demand for real-time IWSNs. The novelty of the proposed method will help to improve the system schedulability. Improving system schedulability will increase network resources. Optimizing the schedulability of the system will improve the performance. We adopted an IEEE 802.15.4 frame format with a variable-slots size that helps divide slots into smaller ones to increase network resources (speed and bandwidth) for IWSN in real-time, improving network resources. The results showed that through our simulations, the Variable-Slot Split Scheduling Algorithm (VSSA) outperformed the existing algorithm by 74% improvement. Performance metrics such as nodes numbers, number of channels, flows, and system utilization were studied. The results of our extensive simulation compared to SSA (Slot-Scheduling Algorithm) from the literature showed that the relationships of acceptance ratio with system parameters in addition to the calculated improved ones. These are the nodes number parameter with 38% improvement, channels number – 58% improvement, and the system utilization improvement by 99%. The improvement in flows number was 24% and in the real-time proportion in flows were 65%. In addition, the improvement in throughput was 50%, and the improvement in communication load was 81%.

Keywords: industrial wireless sensor network, real time, scheduling algorithm, variable-slot split scheduling algorithm.

實時工業無線傳感器網絡的可變時隙分裂調度算法技術

摘要：工業無線傳感器網絡是新興的無線傳感器網絡，因其廣泛的工業應用用途而受到更多關注，例如狀態監測、過程自動化和環境傳感。在無線傳感器網絡中，無線設備可以通過網關一起或在無線設備集群與互聯網域之間交換信息。此外，傳感器技術使用戶可以輕鬆地發現周圍環境並獲取信息，例如溫度測量值。本研究旨在增加按需分配給實時工業無線傳感器網絡的網絡資源（如速度和能量）。所提出方法的新穎性將有助於提高系統的可調度性。提高系統可調度性將增加網絡資源。優化系統的可調度性將提高性能。我們採用了具有可變時隙大小的電氣與電子工程師學會 802.15.4 幀格式，有助於將時隙劃分為更小的時隙，以實時增加工業無線傳感器網絡的網絡資源（速度和帶寬），從而改善網絡資源。結果表明，通過我們的模擬，可變時隙拆分調度算法的性能比現有算法提高了 74%。研究了節點數量、通道數量、流量和系統利用率等性能指標。與文獻中的時隙調度算法相比，我們廣泛模擬的結果表明，除了計算得到的改進參數之外，接受率與系統參數之間的關係也是如此。這些是節點數參數提高了 38%，通道數提高了 58%，系統利用率提高了 99%。流量數提升 24%，流量實時佔比提升 65%。此外，吞吐量提高了 50%，通信負載提高了 81%。

关键词：工業無線傳感器網絡，即时的，調度算法，可變時隙分裂調度算法。

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1. Introduction

Wireless sensor networks (WSNs) were a fairly modern technology tracked back to the beginning of the 1980s when the United States Department of Defense initiated Distributed Sensor Networks (DSNs) program at the Defense Advanced Research Project Agency (DARPA, Industrial Wireless Sensor Network (IWSN) educed from WSN was designed specially, considering the requirements and the industry nature [1]. In the previous few years, the WSN's development in sensor technologies was very popular. The most common sensors are the sensor nodes that limit battery capacity, which lowers a WSN's lifetime. Hence, the need to develop energy-efficient solutions to keep the functions of WSN for the longest of time rises. WSNs are communication infrastructures containing many spatially distributed nodes equipped with micro-sensors. These small devices are used to sense data from a specific area and cooperate, process, and collect them. Then, data are transmitted to a base station. Although WSNs have existed for several decades, they are one of the key components of the Internet of Things (IoT)-based products and services [11]. This work aims to increase the network resources allocated on-demand for real-time Industrial Wireless Sensor Networks (IWSNs) that help to improve the system schedulability. Optimal schedulability is needed in optimizing the system performance.

2. Literature Review

The issue was addressed by proposing a TDMA frame that contains different sizes of slots. Thus, fewer slots (resources) were wasted, and the on-demand slot allocation was achieved. First, the authors in [13] reviewed the transmission matching in the TDMA frame. Then, two scheduling algorithms were proposed: namely, the split scheduling algorithm (SSA) and the double plug-in algorithm (DPA) [13]. Two scheduling algorithms: branch and bound based on the link conflict classification and with low conflict degree. The previous algorithm obtained an optimized schedulable ratio by creating a search tree and adopting conditions for scheduling [12]. A RIVERBED (OPNET) Academic Edition 17.5 simulator, capable of generating valid results and analysis, was used to determine real system behavior.

With this simulation software, the performance of ZigBee-supported star, tree, and grid architectures was compared based on end-to-end delay, throughput, and received traffic parameters. The unit of 3D partition and basic underwater sensor network cluster structure was determined with the arrangement of rotating temporary control nodes in the cluster. The simulation results further verified the sleep-wake scheduling algorithm’s effectiveness [14]. The standard poster correction algorithm was used to find the lowest expensive time-dependent path on the time-space network, which is a solution for each sub-problem. They proposed the Lagrange relaxation solution framework, and numerical experiments were performed on both a small network of artificial and a realistic network adapted from the Chinese railway network [5]. Different strategies were used in the three stages to guide many experimental approaches. In experimental results, the different initial solutions and optimization strategies differently affected the solution’s quality [6]. Our work will use a variable-slot size structure by dividing slots into smaller ones that improve network resources such as speed, energy, bandwidth, and others. By using a Rate-Monotonic (RM) scheduling, the variable-slot structure prioritizes allocations, which is the modern technique to allocate in real-time the stream priority of the systems and in IWSNs. In order to pair the sending and the receiving packets data, the Algorithm of Transmission Matching (ATM) is used. Then using SSA enhancement to schedule the flows depends on the size of the packets.

3. Methodology

In real-time applications of IWSNs such as automatic control and condition monitoring, the sensed data was assumed to be delivered from the source node to its destination within a defined deadline previously, which was decided by the application. In such applications, the presentation of the data within a predetermined deadline ensures that appropriate actions are taken on time. In contrast, the delay in the delivery of data had a negative impact on the effectiveness of the action [4]. Both real-time performance and reliability are two important indicators of the IWSN. Many industrial standards are used in IWSNs that help in Time Division Multiple Access (TDMA), for example, ISA100 and WirelessHART. TDMA frame supports one to two parts of slots in each frame; usually, 10 ms is the duration of each slot that affects the response in transmissibility and IWSNs real-time. Since the transmission's number is large when compared with the length of small packets. We can send control messages and sensor data wirelessly between two machines. However, errors can happen when the position of data is changed between the nodes when we used an unreliable connector when the data arrived lately. Although industrial technology provides real-time wireless and reliable transmission, it cannot provide exact requirements for whole IWSNs. Channel contention will happen if the system does not have an exact schedule because of transmission conflict. Then, the delay in receiving data will occur. To solve those problems, we should have heterogeneous slots (variable slot size) IWSNs.

In most cases, the packet does not require a full-frame capacity to transmit instructions. Here, we adopt a frame model with variable slots size (heterogeneous) to increase network resources for IWSN real-time. Slot length is determined based on packet size that increases the number of slots.

The purpose is to make the schedulability of the IWSN better by using the different sizes of slots for the flows (streams) which cannot be scheduled. For analyzing the feasibility of this variable slot size design, we take the cases when there are only three small slots in each frame, in which the proportion of real-time and traditional slots is $\beta = l/L = 0.3$ [13].

The wireless nodes set N, $e = |N|$, where e is the nodes number in N. Transmission data from source to the centralized controller F is defined as a flow; it denotes a set of flows (streams) in the network by $z = |F|$, where z is the number of the flow in F [13]. The flows (streams) number in each node i can be calculated by using 8 bytes for each packet's flow. In addition, using $((i \times 2) - 1)$ [10] equation to know the nodes number into SSA using $((i \times 3) - 1)$ [10] equation to know the nodes number into VSSA.

3.1. System Design

Wireless nodes comprise a multi-hop wireless network. The design has a centralized controller, a gateway, and wireless nodes, the model's components. It depends on the standard of IWSN such as WirelessHART and ISA100 [13]. It has the prominent features as follows: a fixed-size network, IEEE 802.15.4 physical layer that allows hopping between channels per slot time, and Media Access Control (MAC) layer that runs the multi-channel Time Division Multiple Access (TDMA) protocol as we see in Fig. 2 based on TDMA frame structure in Fig. 1. There is only one centralized controller destination that receives all sensory data. The wireless nodes set is denoted as e is the nodes number [13].

The flow character j is indicated by $\{c_j, t_j, d_j\}$ where c_j is the hops number of transmission (number of hops), each slot transmits one hop, so the flow needs at least c_j slots to reach its destination. The period (number of hops on all paths) is t_j, and the transmission limitation is d_j. The flow (stream) packets are generated by the source with a period of t_j, and these packets travel for c_j hops on the routing path. Each packet is received to its destination before d_j (number of path's statements, In TDMA protocol, all packets transmit under a multi-channel [13].

For regularly scheduled IWSNs under the protocol of TDMA, a slot takes 10 ms duration for transmission. Approximately, if we have 312 bytes, (250 * 1000/100 *8 = 312 bytes) can be transmitted over a single slot since the maximum bandwidth for IEEE 802.15.4 radios used in IWSNs [13]. Fig. 2 is IEEE 802.15.4 frame format, and there is a maximum of 307 bytes of memory space to store sensor data. The variable-slot size structure is proposed in VSSA to improve IWSNs performance. The packet that cannot be scheduled and does not transmit through the regular slots is called a small packet, and the corresponding slot that transmits the small packet is small. According to the small packet's size, the slot is split into small slots, and each slot has 8 bytes.

The small slot is indicated to l, where $l=(((dps*10)/307)+hd)$ ms, dps is the small packet size, 307 is bytes number of memory space to store sensor data, and hd is the header of TDMA [13]. An on-demand parameter β describes the proportion of real-time and traditional slots, and it is stated as $\beta = l/L$, where L is the traditional 10 ms slot [13].

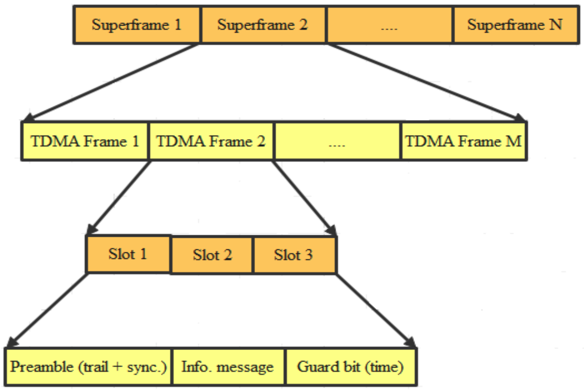

Fig. 1 TDMA frame structure

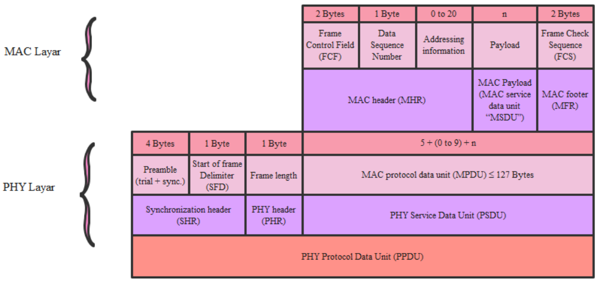

Fig. 2 Format of IEEE 802.15.4 frame

3.2. Transmission Matching

In IWSN, sensors are connected through the lower-power multi-hop wireless mesh. A transmission delay occurs when allocating channels and slots. On account of a significant communication delay that may decrease the achievement of the system or cause errors, we improve network resource allocations before the network runs. However, IWSN cannot run unless all the nodes in the IWSN match with the one-hop away node on its transmission of slots and channels.

Furthermore, the best solution is to use the Algorithm of Transmission Matching (ATM) to pair the receiving, and the nodes are sending for each transmission by variable slot size IWSN. Then, prove if the system performance is independent of the traditional slot partitioning by simulation evaluation regarding the acceptance ratio, which is the proportion of scheduled flows.

As mentioned previously, the transmission matching analysis starts at β=0.3. We suppose all the flows in the system transmit under small slots when there is no ability to schedule the system. Then, we merge the flows of common slots, which cannot be transmitted under small slots called transmission matching (TM, When the packet size is ignored, the slot length can be decreased according to packet sizes. The more slot parts n, the greater numbers of small slots are divided from the regular slot. Then, the case becomes a math problem. Hence, when the minimum bound of the packet is discarded, the system can obtain the same achievement regardless of the β value. Their system has the same performance even if they use the small slot, in light of their system's particular details and the accurate time synchronization. They have been set the small slot to *l* because the system satisfies their variable slot size model regardless of the value of β (or β_i) [13].

3.3. Variables-Slot Split Scheduling Algorithm

In this section, we will display the VSSA for variable slot size IWSN. The main idea of VSSA is to reallocate the small slots for the flows when the system cannot be scheduled. This algorithm works on the cases in which there are three parts of slots; the following algorithm describes VSSA in one frame:

Algorithm. Variable-Slot Split Scheduling Algorithm

```
Start
Void getSystem method
While ((! feof (InputFile))
End While

int LCM method
for(int i = 0; i < tsize; i++)
End for
While (b == -1)
If (x! = t [i]), b ← 1
If (m > t [i]),  m ← t[i], index ← i
End for
If (b == 1),  t [index] ← increment to initialArray [index]
End while
Return t [0] * 2

int priorProcess method
for (int j=0; j<flow; j++)
if (tempArr [2][j] < maxprio && tempArr [0][j]! = 0), maxprio ← tempArr [2][j]
End for
For (i < flow, increment 1)
if (lessPeriod > tempArr [1][i]), prior ← i, lessPeriod ← tempArr [1][i]
End for
Return prior

Void schedule method
For (int i = 0; i < flow; i++)
tempArr [0][i] ← 2 * fl [0][i], tempArr [1][i] ← fl [1][i], tempArr [2][i] ← fl [2][i]
End for
For (t = 0; t < LCM; t++), prior ← priorProcess ()
If (prior! = -1), t, t increment 1, prior
If (prior == -1), t, t increment 1
End for
For (i < flow, increment 1), tempArr [1] [i] increment 1
If (tempArr [1][i] == 0), tempArr [0][i] ← fl [0][i], tempArr [1][i] ← fl [1][i]

Int main method
For (i < flow, increment 1)
sum ← sum increment to (fl [0][i] divided to fl [1][i])
End for
For (i < flow, increment 1)
help [i] ← fl [1][i]
end for
LCM ← lcm (help, flow)
Schedule ()
End
```

The previous algorithm of VSSA is simple and easy. It is briefly:

- First, we allocate the resources using the RM scheduling scheme for all flows. Then we check whether the system is scheduled or not.
- If the system cannot be scheduled, the regular slots are split into a small split by β. After that, the network resources are reallocated again by RM and revise the schedulability. Otherwise, success status is returned.
- The time complexity of VSSA is O (z X e), where z is the number of the flow, and e is the nodes number.

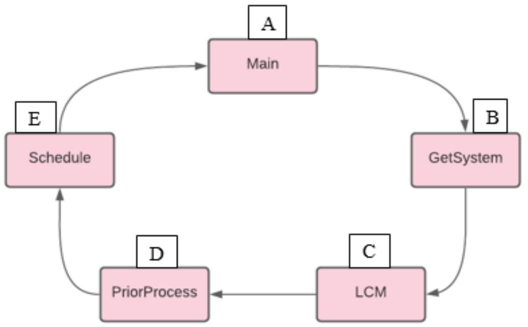

Fig. 3 Flowcharts block

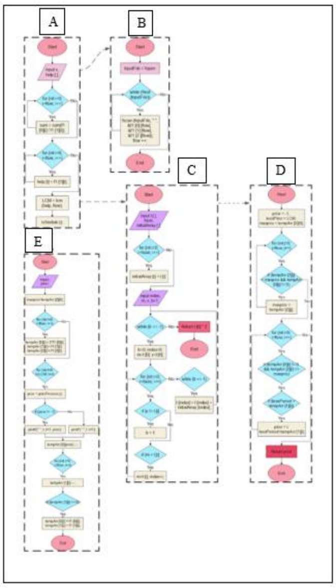

Fig. 4 VSSA flowchart

3.4. Improving Transmission Efficiency

The previous section illustrated VSSA, which provides an approach for improving the scheduling of the system. Suppose a high-priority regular packet occupies a node that may cause a transmission delay for the packets that transmit under small slots and miss the deadline. This work studies the point at which we can make the system perform better and improve the transmission by avoiding unnecessary waits. We analyze with β = 0.3. We use utilization introduced into the RM scheduling algorithm to handle the transmission conflict better and make the system schedulability.

The node *i* utilization in a frame u_i can be demonstrated as $u_i = T_i / T$, where T_i is the total transmission number of slots in node *I* during T, where T is the transmission that contains sending and receiving [13]. Then system utilization is

$$U = \sum_{k=1}^{n} \frac{C_k}{T_k} \; ,$$

where *n* is the number of transmissions in the system, *k* is the number of the flow transmitted through the node *I*, *(or* $\sum_{i}^{e} u_i > m$), where *e* is the nodes number and *m* is the channels number), c_k is the execution time, and T_k is time "deadline" [13]. We can know the channels number by m = (e(e-1))/2 (binomial coefficients equation.

4. Results

In this chapter, we will represent the simulation to evaluate the performance of our proposed algorithm. We determine the proportion of real-time flows of slots stream in F as $B = (F_1 - F_0) / (T_1 - T_0)$, where F_1 and F_0 are the number of flows in node *i* "F_i," and T_1 and T_0 are the execution time in node *i*. The algorithms are implemented in the C++ language, and those codes are executed on a Windows machine with (1.20 GHz) CPU and 4 GB memory. The constants used in this chapter are L = 10 ms, *l* = 3.3 ms, and β = 0.3.

4.1. Simulation

The simulation runs on a mathematical model that describes the system. In the simulation, one or more of the mathematical model variables is changed, and the resulting changes are observed in the other variables. Simulations allow users to predict a real-world system's behavior [2]. Simulation helps to improve systems by making necessary changes and getting good results [2].

We assess the proposed VSSA using the RM scheduling policy algorithm. We create test cases for each simulation parameter configuration randomly to show the applicability of our algorithm. In each configuration, the system performance is assessed by the acceptance ratio, which is the ratio of scheduled flows. Simulation parameters are summarized in Table 1.

Table 1 Simulation parameters

Parameter	**Description**	**Parameter**	**Description**
e	Nodes Number	L	The length of slot
z	Flows Number	*l*	The length of small slot
U	Utilization of system	B	Proportion of real-time flows
β	The proportion of real-time and traditional slots		

Execution time or CPU time for a task is determined as the time the system spends on performing that task, including the time spent executing the runtime or system services on its behalf. The mechanism used to measure the execution time is determined. It is the specified execution in which the task is loaded with an execution time consumed by the interrupt processors and runtime services on behalf of the system.

4.1.1. Execution Time Simulation

Fig.. 5 depicts the difference between SSA and VSSA. The SSA is an algorithm that improves the technical division to divide the packet into 2 parts, which able each part to be an input with a slot. The VSSA is an algorithm that improves the technical division to divide the packet into 3 parts, which able each part to be an input with a slot. Our simulation is done in execution time, and it is less than the SSA's execution time. So, our algorithm's speed is more than SSA's speed, as we will show later. One of the main important goals of our proposed work is to increase the network resources allocated on-demand for real-time IWSNs, which helps improve the scheduled systems. When the execution time's speed is increased, all of the energy, throughput, bandwidth, and their quality will be increasing. In addition, any noise does not affect the energy, such as channel contentions and transmission conflicts. Then, $P_{m(VSSA)} < P_{m(SSA)}$. In addition, when the speed increases, the energy will be consumed, and transmission delay will not occur. In addition, the improvement of this simulation is 98%, as depicted in Fig..

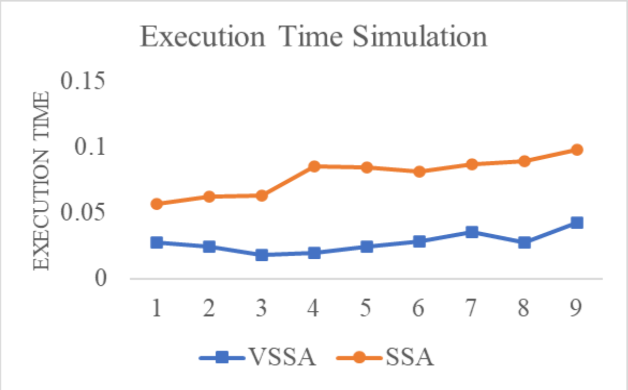

Fig. 5 Execution time in SSA and VSSA

4.1.2. Energy Consumption Simulation

This section will display the energy that each node consumes to send a packet to another node. Energy (Joule) is transferred from one node to another node necessary to operate or send packets, and the distance between those two nodes is L (meter). The voltage on the power line is (V) Volt, the current is (I) Ampere, and the resistance of the line is (R)Ω [7].

In execution time simulation, we insert the same packets into C++ codes then, we take the time that the packets took it to be executed. This simulation aims to see the difference between the execution time that VSSA takes and SSA execution time.

Fig.Fig. 6 depicts the second simulation, which shows the difference between the energy consumption that SSA needs to transfer packets and the energy that our algorithm (VSSA) needs. Our purpose in this simulation is to show how our simulation consumes less energy than SSA, which assists in increasing the network resources. At first, we take the number of the flow of each run time and multiply it to 8 "slot's sizes," then multiply it to 8 (convert Byte "in general, slot size is 8 Byte" to bits, For example, if the flow number is equal to 2 so, the packet takes 2 slots to arrive at the destination (each slot takes one flow) then, multiply (2*8 to 8) to convert bytes to bits (signals unit is a bit, Then, we adopt the CC2530 sensor type, which is based on the energy model of WSNs to calculate the energy consumption by *Energy consumption = Energy * Number of bits*, and its unit is Joule [3]. The improvement is 24%, as depicted in

Fig..

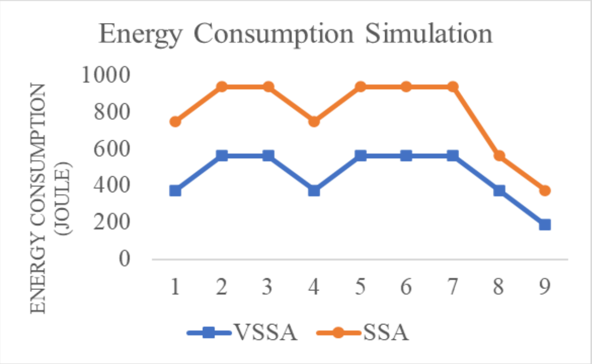

Fig. 6 Energy consumption simulation

4.1.3. Distance Simulation

This section will display the distance that each node needs to send a packet to another node. The distance is the length of the space between the two points and is measured in meters. Most WSNs localization systems use distance estimation techniques to calculate the position of the nodes [9]. At the speed of light, electromagnetic radiation travels at c = 299792458 m/s. the distance between sender and receiver is d = c * t, where t is flight's time "execution time" [9].

Fig.Fig. 7 depicts the distance simulation that shows the difference between the distance SSA requires to transfer packets and the distance that our algorithm (VSSA) requires. Our purpose in this simulation is to show a shorter distance between two nodes in VSSA that has a higher probability from a direct communication link (the distance that the SSA requires is higher. So, it takes more flight time then, which increases the delay probability. The improvement is 99%. As

Fig., we use linear distance theory to extract the distance between two nodes [9]. The improvement here is 52%.

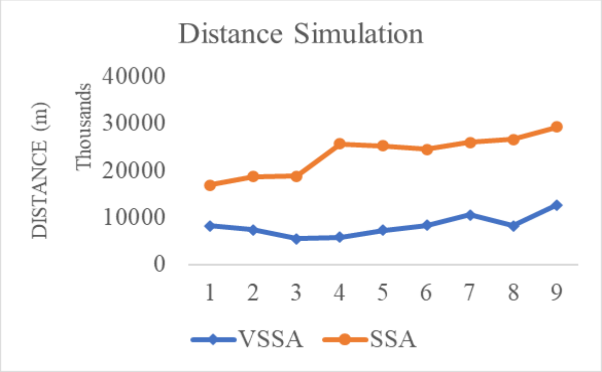

Fig. 7 Distance simulation

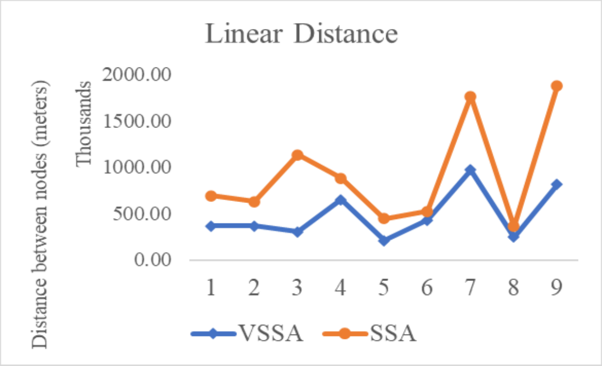

Fig. 8 Distance between nodes

4.2. Results

We can find many relationships between the acceptance ratio and system parameters, such as between the acceptance ratio and the nodes number, between the acceptance ratio and the channels number, and others. In

Fig., we depict the relation of the acceptance ratio with the nodes number, when m is the channels number equal to 1215, flows number is z = 22, the real-time proportion in flows is B = 1.4, the utilization of the system is U = 3.03, there is a relationship. The acceptance ratio under RM scheduling policies satisfies VSSA > SSA, and all the results containing increasing nodes number e are increasing. The improvement here is 38%, as depicted in

Fig..

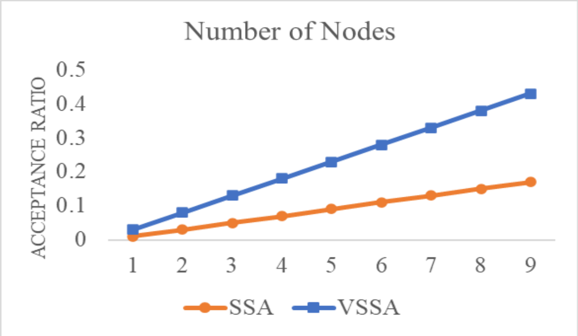

Fig. 9 Relation of the nodes number with the acceptance ratio

Fig.4 decipts how the acceptance ratio and the number of the flows when the nodes number is e = 126, the utilization of the system is U = 3.03, the channels number is m = 1215, and the real-time proportion in flows is B = 1.4. Acceptance ratios decrease compared to an increase in the number of the flows because more conflicts increase the increased workload. Because small slots release more unoccupied resources, the reduction in the SSA framework is much slower than in VSSA, thus improving resource utilization. Since VSSA makes the most use of resources, it performs better than the other algorithm, and the improvement here is equal to 24%, as depicted in
Fig.4.

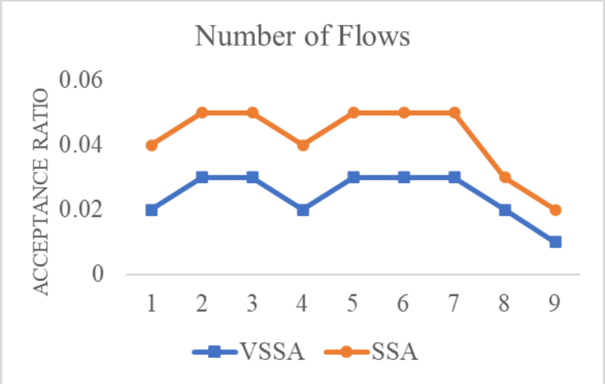

Fig.4 10 Relation of the number of the flow with the acceptance ratio

Fig.Fig. 11 depicts the relation between the acceptance ratio and the channels number. When the nodes number is e = 126, the number of the flow is z = 22, the real-time proportion in flows is B = 1.4, and the utilization of the system is U = 3.03. The performance of VSSA is improving the fastest, especially in the range of (0.4– 0.6, So, the use of VSSA improves the slot's system performance, and the improvement is 58%, as depicted in
Fig..

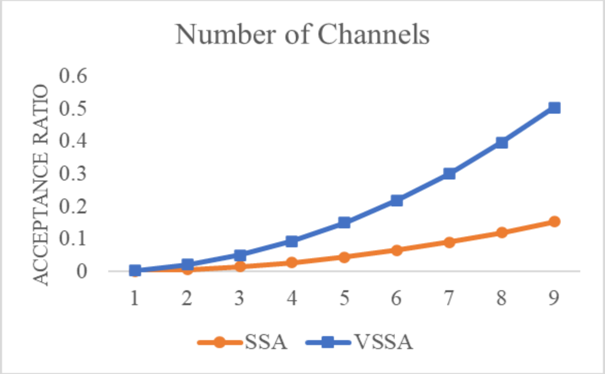

Fig. 11 Relation of the channels number with the acceptance ratio

Ошибка! Источник ссылки не найден. Fig. 12 depicts the real-time proportion in flows relationships with the acceptance ratio. When the nodes number is e = 126, the channels number is m = 1215, the number of the flow is z = 22, and the utilization of the system is U = 3.03. Because VSSA gradually degrades to SSA, a large flows number is sent in short periods. So, the acceptance ratios of SSA and VSSA gradually converge. In addition, the improvement here is 65%, as depicted in **Ошибка! Источник ссылки не найден.**2.

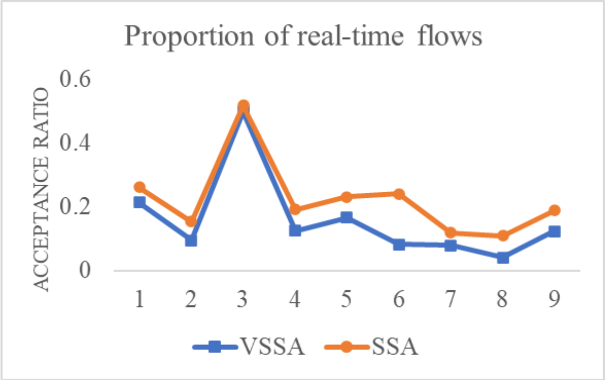

Fig.5 12 Relation of the proportion of the flows in real-time with the acceptance ratio

Fig.6Fig. 13 depicts the acceptance ratio's relationships with the system utilization. When the nodes number is e = 126, the flows number is z = 22, the channels number is m = 1215, and the real-time proportion in flows B = 1.4. The probabilities of transmission conflicts and channel contention increase with increasing utilization. So, when system utilization changes from 0.01 to 0.16, both SSA and VSSA performances are decreased. Utilization is a good measure for evaluating the "quality" of a scheduling algorithm. The improvement is 99%, as depicted in
Fig.6.

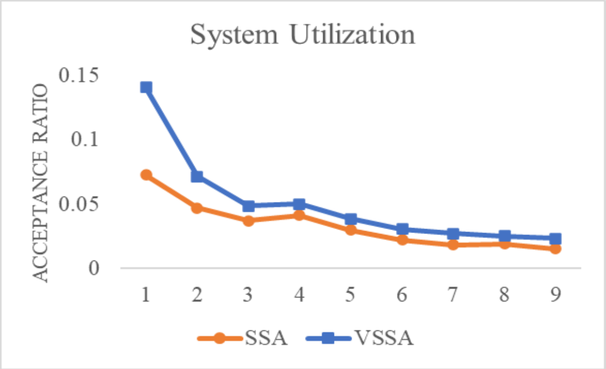

Fig.6 13 Relation of the system utilization with the acceptance ratio

The transmission rate is the data transmitted volume through a channel's transmission or over a data interface in a specific unit of time. Baud or bits/s (bps) is a unit that is used. Network throughput is the rate (bps- bits per sec or PPS – packets per second) at which bits or packets are delivered successfully through a channel. So, all nodes can gather received packets to calculate the value of a small network or network segment [8].

Fig.7Fig. 14 depicts the transmission rate (throughput) in VSSA that estimates the maximum throughput for each node compared to SSA. The SSA's throughput decreases with distance until close to zero. More efficient modulation can achieve much higher peak throughput. The modulation, which can achieve much higher throughput, is more efficient. The improvement is 50%.

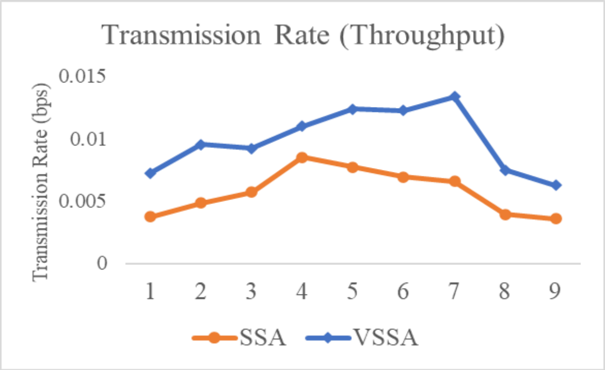

Fig.7 14 Transmission rate (throughput)

The communication load is the amount of traffic the Access Points (APs) should forward to the network or the associated clients. It is dependent on the average interval transmission for each node and its neighbors.

The communication load P_d (i, j) is defined by

$$P_d(i,j) = \frac{2^{R_0}-1}{-\log(P_0^s)},$$

where R_0 is the transmission rate (throughput), and P_0^s is the successful transmission probability. As shown in Fig.8, VSSA has a minimal communication load compared with SSA, and it is better than SSA for a node. The improvement is 81%.

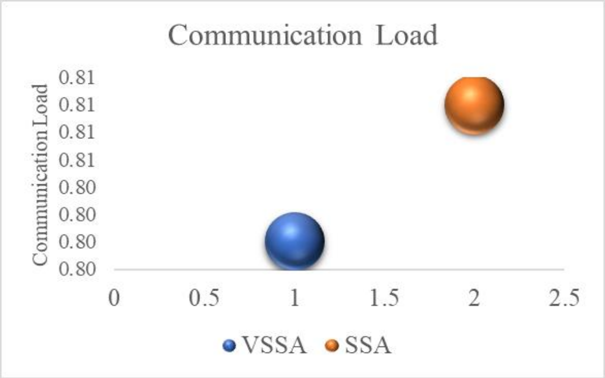

Fig.8 Communication load

5. Conclusion

IWSN contains two important indicators, which are performance and reliability in real-time. IWSNs use many industry standards that are widely used, which are based on Time-Division Multiple-Access (TDMA) frame, such as ISA100 and WirelessHART. Those standards are helping to increase the reliability and the real-time requirements in IWSNs. TDMA frame supports one to two parts of slots in each TDMA frame. Usually, 10 ms is the duration of each slot. Increasing the network resources allocated on-demand for real-time IWSNs helps to make the system's schedule better. Ensuring that data is not delayed or the errors will not happen by providing reliable transmissions, real-time IWSNs, and an accurate schedule. Because of that, we enhance SSA by our Variable-Slot Split Scheduling Algorithm (VSSA, This model prioritizes allocations using a rate-monotonic (RM) scheduling scheme, the latest technique for flow priority allocations in real-time IWSNs. In addition, the algorithm of transmission matching which used to pair the receiving and the sending nodes for each transmission by variable slot size IWSN, VSSA. The novelty of this research is that a significant improvement led to an increase in the network resources such as speed and energy, which are very important metrics especially in IWSN.

The results were divided into two main parts. The first part shows the simulation we used to compare the original method (SSA) and our method (VSSA) by implementing both using C++ language. The simulation shows the difference in execution time, energy consumption, and distance in both and how network resources in our method were increased. The results also show that the Variable-Size Slot Scheduling Algorithm (VSSA) outperforms the existing algorithm by 74% improvement through our simulations. At the same time, execution time was less than the SSA's in execution time.

Regarding the energy consumption in VSSA is less than SSA, and the traveled distance of SSA is more than the traveled distance of VSSA when the execution time was fixed. The simulation results assist in increasing the network resources, such as increasing the nodes number and the channels number. Finally, we displayed the relations between the acceptance ratio and system parameters, such as the nodes and channels numbers. Moreover, we displayed the acceptance ratio relations with system parameters and the calculation of improvement in the nodes number with 38% of improvement, and for the channels number – 58% of improvement.

By analyzing the characteristics of the different scheduling methods, we will study how to improve VSSA and suggest variable slot scheduling policies based on VSSA. We also plan to study the lifetime of variable slot IWSNs.

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