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Research of Wireless Sensor Monitoring Network of Melon Fly under Different Temperatures and Other Environmental Conditions

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Abstract: *In order to achieve multi-point, highly efficient and real-time wireless transmission of data about melon fly monitoring under various temperatures and other variable environmental conditions, this paper proposes and builds a model of a melon fly monitoring system with a wireless sensor network. Combined with multi-hop wireless sensor networks suitable for Adaptive Ad Hoc Transmission Control Protocol (ADTCP) algorithm, the transmission-limited congestion window is a method to reduce network congestion, simulate the aggregation node of the sensor network through a wireless transceiver platform, and finally to compile monitoring data in a central computer. The proposed scheme can effectively mitigate congestion problems of the wireless sensor network for monitoring melon flies at the aggregation node, can improve the data transmission performance of the monitoring network, and can adapt to various environmental conditions.*

Keywords: *Melon fly, Insect monitoring, Wireless sensor network, Environmental conditions.*

Introduction

Bactrocera cucurbitae (Coquillett), i.e., melon fly, is a kind of important pest which uses multiple host plants, mainly fruit and vegetable plants. Due to the relatively long lifespan of the adult melon fly and their strong capacity for long flights, they can oviposit in suitable hosts in a wide range of territory Therefore, strengthening our capacity for remote real-time monitoring of adult melon flies is extremely important [10, 13]. The melon fly uses flight migration as a survival strategy for its populations, abandoning habitats that have become inhospitable due to either geography or seasonal changes, and with its wide flight range increases the number of orchards it infests [1, 6]. It is difficult to achieve accurate real-time monitoring of melon flies in such a wide range, thus hindering appropriate prevention-control measures based on the constantly changing temporal and spatial population density of melon flies. Jang [8] put forward a remote pests monitoring system based on wireless communication technology. This system can ecologically monitor pests, automatically report real-time environmental conditions and also can trap, count and classify insects. Wen et al. [18], based on machine vision technology, made flight trajectory tracking of *Bactrocera dorsalis* related species of the melon fly, and completed *B. dorsalis* monitoring by using the method of cann edge detection and break background subtraction. Wen then implemented individual marks in sequential frame images in various orange *B. dorsalis* and trajectory tracking by the algorithm CCMSPF (Connected Component & Particle Filtering Based on Mean Shift). However, the saved images in the research could not achieve real-time monitoring and processing on the *B. dorsalis*. The Internet of Things technology is a novel distributed sensor network and information transmission network integrating various sensing technologies, modern communications technology, artificial intelligence, automatic control, etc., which has been widely used in insect monitoring and early warning, agricultural traceability, etc. Xiao et al. [19] designed *B. dorsalis* trapping monitoring equipment based on the Internet of Things technology, the apparatus comprising three main parts with trapping monitoring devices, solar-powered equipment and monitoring and control devices, can automatically track, recognize and compute the real-time number of *B. dorsalis*. From the above studies, it is known that conducting long-term monitoring of the melon fly over a long distance is feasible, but monitoring large numbers of melon flies and retaining images remains problematic [2, 3]. Increasing the number of monitoring points results in melon fly monitoring data becoming prone to network congestion during transmission over a wireless network. Additionally, complex meteorological conditions in orchards and other monitoring areas limit the real-time monitoring capability of the melon fly [5, 14]. Therefore, it is necessary to develop a new melon fly monitoring method to reduce network congestion, achieving efficient multi-point data and real-time wireless transmission of the monitoring process.

Wireless sensor network model of melon fly monitoring

The system for monitoring melon flies with a wireless sensor network consists of sensor signal acquisition, wireless data transmission, and data management and analysis, as shown in Fig. 1. The whole monitoring system is composed of a plurality of relatively independent sub-miniature wireless sensor monitoring networks. In the acquisition portion of the melon fly monitoring data signal, the system collects data with a number of sensor nodes (monitoring nodes) distributed throughout the monitoring area of the melon fly, constituting a wireless sensor network. Data collected by the sensors is transmitted to the wireless transceiver by the transmitter module. The wireless data transceiver transmits monitoring network data to aggregation node in the sensor node monitoring. This system not only plays a role in converge of data, but also has the functions of noise removal and amplification of the melon fly monitoring signal. In the sensor networks, aggregation nodes with multiple hops function can collect monitoring data forwarded to the next hop. In large-scale monitoring of the melon fly, the aggregation node can effectively forward data, which can significantly reduce the complexity of network monitoring collection, to achieve efficient transmission of monitoring data. Sensor data is transmitted to the data terminal for the next step of data processing, and the final data is transferred to the computer for collection and analysis. Simultaneously, the monitoring client analyzes the received monitoring data, if required, and all monitoring data can also be connected through the internet making the data accessible to various individuals for use upon request.

In the system for monitoring melon flies with a wireless sensor network, monitoring sites usually consist of a large number of sensor nodes, so the network coverage area is much larger compared to data from other types of monitoring systems. Based on previous research, melon fly monitoring is implemented through the application of infrared sensors to monitor flight status and flight paths in the monitoring area. Sensor nodes are deployed in the monitoring system for real-time acquisition of the melon fly population density, flight time and time period. In addition, it can dynamically release melon fly monitoring data through a self-organizing network to the remote monitoring center. Taking into account the mobility and randomness of adult melon flies, many sensor nodes are needed in the monitoring area (Fig. 2), which facilitates the construction of wireless sensor networks and thus maximizing the collection of melon fly monitoring data. In the monitoring process, no monitoring data is missed, which is different from the conventional sensors monitoring networks [9, 11, 15] such as environmental monitoring. Because the overall flight patterns of melon flies change slowly, the collected data has great similarity at the before and after points in time, resulting in potentially large amounts of redundant data from the monitoring nodes to the aggregation nodes. This means that reliability requirements are not high for the uplink data transmission (monitoring nodes transfer to aggregation nodes). However, the melon fly monitoring network still needs very reliable transport protocol for the uplink transmission direction.

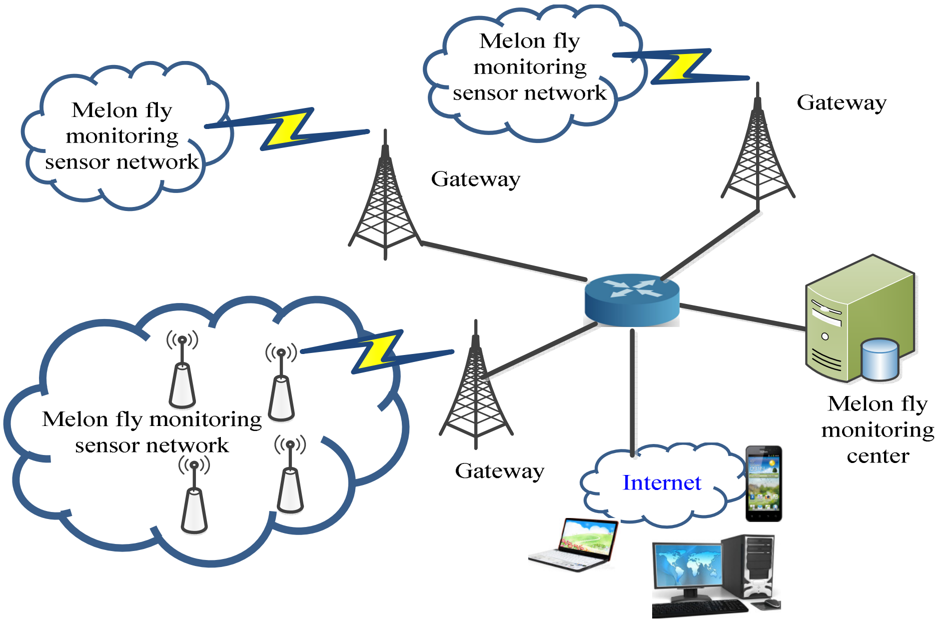

Fig. 1 Wireless sensor network model of melon fly monitoring

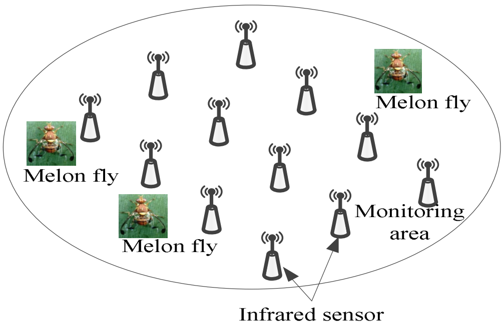

Fig. 2 Schematic diagram of melon fruit fly monitoring

Enhanced transmission to data of melon fly monitoring network

Adaptive Ad Hoc Transmission Control Protocol (ADTCP) is a suitable control protocol for resolving wireless multi-hop network congestion, and is applicable to wireless sensor networks as well [4]. It uses a port-to-port control strategy which takes advantage of the network status and determines the identification of congestion and non-congestion with combined use of multiple parameters. The ADTCP design uses four end measurement parameters, namely the delay difference (IDD), throughput (STT), the ratio of out of order packages (POR) and packet loss rate (PLR). The specific calculation method is as follows:

$$IDD = \left(A^{i+1} - S^{i+1}\right) - \left(A^{i} - S^{i}\right), \tag{1}$$

where A^i denotes the timestamp of the arrival of the *i*-th data packet at the receiving end in transport connection; S^i refers to timestamp of when the *i*-th data packet was sent by the sender. IDD reflects the congestion level through instantaneous changes in the queue size in the forwarding link intermediate node, and it is rarely affected by channel errors, so compared to the random loss, delay fluctuation it is much less in successive packets.

$$STT = N_p\left(T\right)/T, \tag{2}$$

where $N_p\left(T\right)$ is the number of received packets within a time period of *T*. Like IDD, short-term throughput also can reliably reflect the multi-hop network congestion, but it observes the congestion status in a time gap. Compared to IDD, short-term throughput is not sensitive enough to packages received out of order, so short-term throughput can accurately determine the routing changes on the transmission path. However, in a mobile multi-hop network, especially in cases with high numbers of moves and frequent route changes, single use STT is susceptible to be affected by burst channel errors, interrupted network connections and the change rate of TCP sending port. ADTCP jointly determines the extent of congestion status by ADD and SET network.

$$POR = \frac{N_0\left(T\right)}{P_n - P_{n-1}} \times 100\%, \tag{3}$$

where $N_0\left(T\right)$ is the number of packages received out of order within a time interval *T*; P_n is the maximum numerical order of packages received out of order within the time interval; P_{n-1} is the maximum numerical order of packages received out of order in the previous time interval. If a data packet A is sent before a data packet B, but B arrives earlier than A, then the packet A is considered out of order. When routes change, there may be simultaneous multi-hop transmission paths during routing switching in the networks. Transmitting packets through a new path may cause more to arrive at the receiving end before packets transmitted through the former path, which causes many packages to be out of order.

$$PLR = \left|1 - \frac{N_p\left(T\right)}{P_n - P_{n-1}}\right| \times 100\%, \tag{4}$$

where P_n is the maximum numerical order of packages received in the time interval; P_{n-1} is the maximum numerical order of packages received out of order in the previous time interval. The parameters calculate the amount of packet loss in the current receiving window and time interval, which can reflect the frequency of the channel where the error occurred.

Compared with single measurement parameter, multiple parameters that together determine network status will result in greater accuracy. At the same time, the sender takes more appropriate measures to adjust the congestion window size to enhance the transmission performance of the network. In the process of joint-parameters determining congestion recognition, the network will be congested when the delay difference of continuous data packet transmission is higher and the short-term throughput is lower; otherwise, the network is not congested. So it is necessary to set the appropriate threshold high or low for delay difference of continuous packet transmission and short-term throughput. When the delay difference of continuous data packet transmission is higher than the high threshold and short-term throughput is lower than the low threshold, it indicates network congestion; in other cases, the network will not be congested. It is very important to set high and low values, but they are determined by the specific network environment. Experimental results show that setting both high and low values at 30% will achieve better recognition. Joint parameter value determining congestion status is shown in Table 1. An effective congestion control algorithm is able to timely detect various network conditions and properly analyze the kinds of network conditions, and finally adopt appropriate measures according to network conditions. ADTCP is a multi-parameter method, which can effectively improve the accuracy of monitoring and make an accurate judgment between congestion and non-congestion, thereby greatly improving the transmission performance of the network.

Table 1. Judgment of network status conditions and circumstances of relevant parameters

Network status	IDD and STT	POR	PLR
Congestion	(High, Low)	N/A	N/A
Channel error	NOT (High, Low)	N/A	High
Route change	NOT (High, Low)	High	N/A
Path disconnection	(N/A, ≈0)	N/A	N/A
Network normal	Default		

In this study, the congestion window limit of the sending side is set to avoid an excessive increase in the congestion window. Based on spatial multiplexing combined with real-time status of the network, an improved dynamically adjusting method for the upper limit of the congestion window is put forward. Namely, upon encountering a higher packet loss rate, reducing the amount of transmitted data will in large extent reduce data competition in the wireless link; and at a lower packet loss rate, increasing the amount of transmitted data will improve network monitoring performance to maintain stability in hostile environments encountered during the monitoring process. When the number of round-trip-hop paths is less than 4, the upper limit is set at 2. From interference analysis of the above wireless link competition, we can see in the case of short-chain (i.e., 1 or 2 hops) there is no self-interference in the MAC layer transmission. Therefore, it is possible to appropriately increase the number of windows value. Although flight patterns of melon flies display features of randomness and mobility, aggregation features are still present. Therefore, a very large amount of data is collected in melon fly monitoring, which easily leads to data transmission congestion in wireless sensor networks, having an overall detrimental effect on the entire monitoring network. In this study, the algorithm for wireless sensor network congestion is improved by adjusting the upper limit of the congestion window. The improved algorithm firstly adjusts the upper limit of the congestion window to increase the amount of data sent to improve the adaptability of the MAC layer transmission, secondly adjusts the growth rate of the congestion window, and finally levels out the calculated packet loss rate, thus not only protecting the reliability of data transmission, but also easing the congestion in the monitoring network data and ensuring data transmission stability in various temperatures and other variable environmental conditions.

The experimental simulation and analysis

In order to better test the performance of the wireless sensor melon fly monitoring network, the improved transmission scheme is simulated in OPNET, with parameters set as follows. MAC layer selects the IEEE 802.11 standard based on competition scheduling scheme; for continuous data transmission, bandwidth is set to 2 Mbps; the operating frequency 2.4 GHz; the transmission distance 250 meters; the interference distance 550 meters. TCP Reno, ADTCP, A^2DTCP and improved algorithms proceed to TCP performance simulation [7, 12, 16-17]. Two kinds of experimental scenes are set; namely, chain scene and grid detect scene. These two scenarios have features of full coverage for insect flight monitoring and multi-level combination, thus maximizing the monitoring of flight conditions of melon flies.

Performance analysis in chain monitoring network

In the chain monitoring graph shown in Fig. 4, the distance between two adjacent nodes is 200 m, and the direction of data flow transfer is from node 1 to node 13, with a total of 13 nodes. We chose hop count in different scenes such as 2 jump, 4 jump, 6 jump, 8 jump, 10 jump, 12 jump, and count the throughput at different hops with different algorithms.

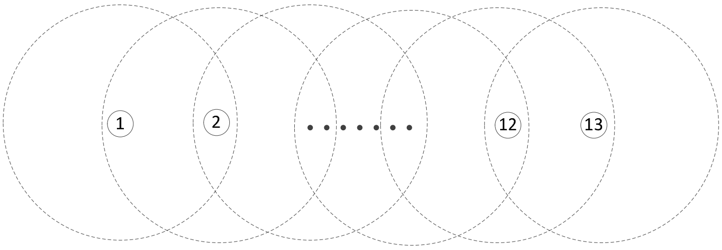

Fig. 4 Chain monitoring

The improved program and changes in the throughput of TCP Reno 6 jump chain monitoring are shown in Figs. 5 and 6. It can be seen that the improved algorithm performs better than Reno not only in average throughput, but also in reducing the fluctuations in throughput. Since the improved program can adjust the sender's sent data traffic according to network status and the path hop count, it can better adapt to changes in network state. When the network status is poor, congestion can be reduced by reducing the amount of transmission, and less package loss resulting in throughput not decreasing too quickly.

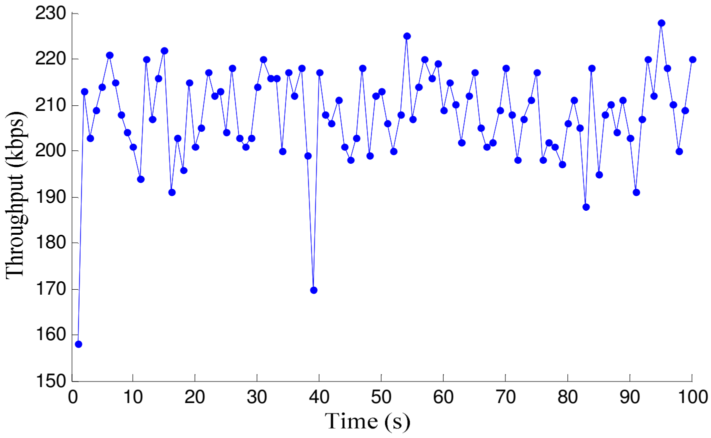

Fig. 5 Throughput of improved algorithm in 6 jump chain monitoring

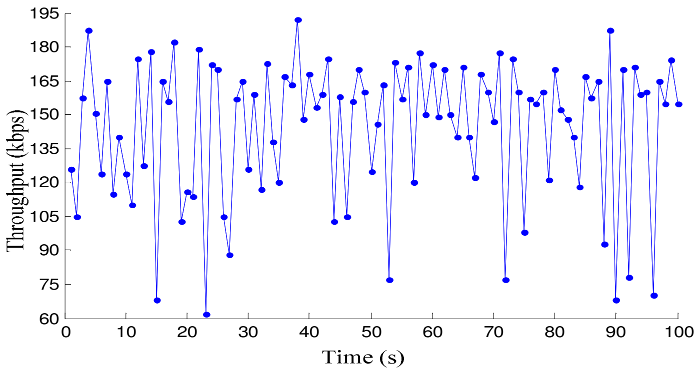

Fig. 6 Throughput of TCP Reno in 6 jump chain monitoring

Comparing throughput in a chain detect scene in a single TCP stream between different hops, with increasing hop count, the average throughput of the network shows a downward trend (Fig. 7). In the chain monitoring figures, each of the monitoring nodes is static; when the path hops is 2, there is little difference in the throughput of four kinds of TCP algorithm. This is due to the relatively simple network status at this time, with no route changes, relatively light channel competition, the nodes being able to detect whether other nodes are sending data, no hidden terminal issues, and the performance of the network is mainly directed by the channel bandwidth. The level of competition for channel access increases with an increase of the number of hops, and increased data will also increase the probability of the occurrence of random collisions. By this time, with the network status relatively complex, the improved algorithm can make full use of the Path Len to control the congestion window within the range of a specified value and have a good inhibiting effect on TCP greed. This relieves MAC layer link competition, resulting in less packet loss, throughput not quickly dropping, improved TCP performance, and better stability of data transmission under various temperatures and other variable environmental conditions in the process of monitoring melon flies. The proposed improved algorithm, ADTCP and A^{2}DTCP all have a greater increase in throughput than TCP Reno, especially when there is a larger number of hops. Out of the four algorithms, the proposed improved algorithm shows the best performance.

Performance analysis in grid monitoring network

The grid monitoring in Fig. 8 shows a total of 7×7 nodes, including both horizontal and vertical directions of the data stream.

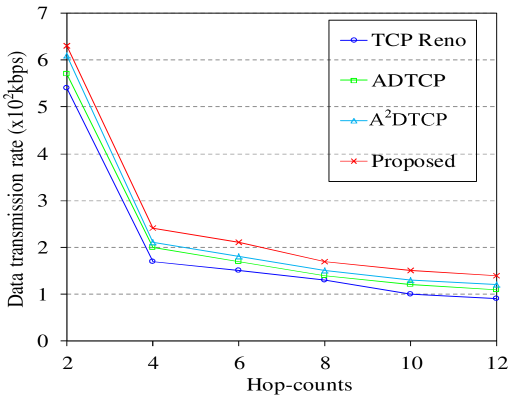

Fig. 7 Comparison in throughput of a single TCP traffic flow between various hops in chain monitoring

Fig. 8 7×7 grid monitoring

The performance of the network is measured by various data streams and directions. There are in total two parallel data streams (from node 1 to 7, and from node 22 to 28), 4 parallel data streams, (a set of nodes in the middle of each parallel flow), 7 parallel data streams, and 14 cross-flow (seven streams respectively in horizontal and vertical directions).

In the grid network (7×7) performance of different TCP algorithms for multiple data stream transmission at the same time is shown in Fig. 9.

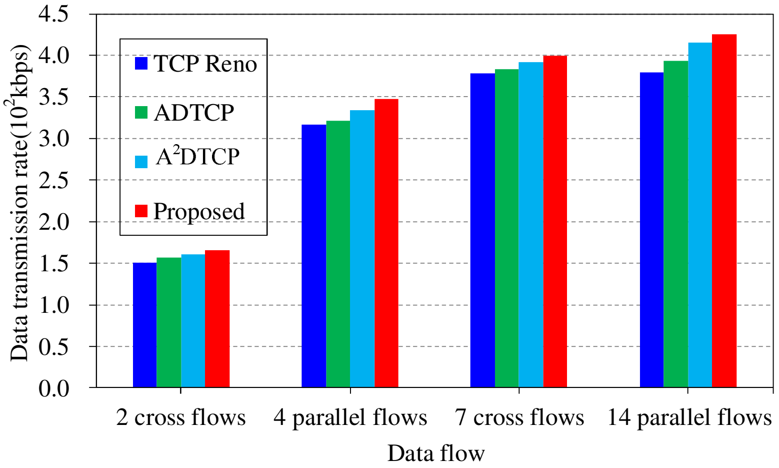

Fig. 9 Comparison of throughput performance of TCP in grid monitoring

When there are only two parallel flows network resources are more plentiful, and the performance difference of the four kinds of TCP algorithms is small. When there are 4~14 streams, the average throughput of the network changes slightly, but is relatively stable. With TCP traffic continuously increasing, the competition between the data flows becomes more and more intense, and the throughput of a single stream becomes smaller and smaller. ADTCP, A^{2}DTCP and the improved algorithm is higher than Reno in throughput, with the improved algorithm performing the best.

Summary

In this research, a model of a wireless sensor network for monitoring melon flies is constructed, along with its network monitoring structures, the key components of which are identified. Combined with ADTCP algorithm applicable to multi-hop networks, a control algorithm for wireless sensor networks congestion is put forward. It can effectively solve the problem of congestion that can easily form in the aggregation node as a result of large amounts of monitoring data, which improves data transfer performance in network monitoring. Experimental results show that the proposed improved algorithm in two different scenarios can effectively improve the throughput in network node, improve transmission performance of monitoring data in a wireless sensor network, and maintain monitoring data transmission stability at various temperatures and other variable environmental conditions.

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