KRILL HERD OPTIMIZATION ALGORITHM BASED ENERGY HARVESTING METHOD FOR TCP TRANSMISSION OVER COGNITIVE RADIO NETWORKS

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ABSTRACT:

The last decade has witnessed an unprecedented growth of mobile data traffic and energy consumption in wireless networks. Energy consumption can incur greenhouse gas emission and high expenditure for maintaining wireless network operation. To reduce the energy consumption, most of the previous works have so far considered improving the energy efficiency of various wireless networks. However, these fail to optimize the energy efficiency of transmitting TCP (transmission control protocol) applications. In this paper, we consider an optimization based technique for reducing energy consumption for transmitting TCP applications in CRNs. In particular, we design an energy-efficient krill herd algorithm (KHA) based TCP transmission scheme for CRNs, which takes into account spectrum sensing, spectrum access, MCS, transmission power, and TCP packet length to enhance the energy efficiency.

I - INTRODUCTION

The Transmission Control Protocol (TCP) is intended for use as a highly reliable host-to-host protocol between hosts in packet-switched computer communication networks, and interconnected systems of such networks.

TCP is a connection-oriented, end-to-end reliable protocol designed to fit into a layered hierarchy of protocols which support multi-network applications. The TCP provides for reliable inter-process communication between pairs of processes in host computers attached to distinct but interconnected computer communication networks. Very few assumptions are made as to the reliability of the communication protocols below the TCP layer. TCP assumes it can obtain a simple, potentially unreliable datagram service from the lower level protocols. In principle, the TCP should be able to operate above a wide spectrum of communication systems ranging from hard-wired connections to packet-switched or circuit-switched networks.

The last decade has witnessed the marvelous growth of mobile devices (e.g., smartphones and tablets). The popularity of smart mobile devices has led to numerous innovative mobile applications, such as autonomous vehicle systems, location-based mobile services. Enjoying these mobile applications brings an unprecedented growth in mobile data traffic in wireless networks. Wireless networks have applied various wireless communication technologies, such as massive MIMO (multiple input multiple output), D2D (device-to-device) communications, mm-Wave (millimeter wave) communications, CR (cognitive radio), to accommodate the increased mobile data.

On the other hand, the last decade has also witnessed the energy consumption of wireless networks. It is well-known that energy consumption can incur greenhouse gas (GHG) emissions that can affect the climate. The ICT (Information and Communication Technology) industry consumes the energy that accounts for 3% of all industries' total energy consumption and causes 2% -4% of carbon dioxide emissions. In particular, wireless networks are the primary sources of consuming energy. Besides the GHG emission, the energy consumption of wireless networks can also cause high expenditure for maintaining wireless network operation, which results in high cost of customers' purchasing mobile services as well. Therefore, we need to take energy consumption into account when designing protocols and schemes for wireless networks.

Researchers have so far considered improving the energy efficiency of various wireless networks. Some previous works fail to optimize the energy efficiency of transmitting TCP (transmission control protocol) applications, and hence may not indeed lead to energy-efficient TCP transmission in wireless networks. The reason is that data transmission at the physical layer does not consider packet loss and retransmission that are not negligible due to the poor quality of wireless links. In particular, TCP is one of the most popular transmission protocols used for many Internet applications, such as WWW, FTP, streaming media applications, etc. Thus, it is necessary to consider the energy efficiency of transmitting TCP applications in a wireless network.

To be more prominent, TCP transmission much easily suffers from performance degradation in CRNs. The reason is that secondary users in CRNs have no exclusive spectrum access, which may incur a high packet loss rate. In practice, cognitive radio technology has been considered as one of the ideal candidate technologies in future 5G wireless communication networks. Therefore, we have a strong motivation for carefully addressing the problem of energy-efficient TCP transmission in CRNs.

Some previous works have studied the problem of energy-efficient TCP transmission in wireless networks. For example, Chen et al. propose to balance TCP throughput and energy consumption for delivering content in heterogeneous wireless networks. Wu et al. propose an analytical model, capturing the tradeoff between energy consumption and distortion rate, for multipath video transmission in heterogeneous wireless networks. Wang et al. propose to control energy efficiency, round trip time (RTT), and path loss rate for adjusting the increment of the congestion window in wireless networks. However, these works fail to consider the energy efficiency of transmitting TCP applications in CRNs. More importantly, they do not improve it in a unified way, which can affect CRNs' energy consumption significantly. For instance, a high-order modulation and coding scheme (MCS), leading to high data rate, may incur high bit error rate for failing in combating the fading and shadowing effects, consequently causing high frame error rate at the link layer (or/and high packet loss rate at the TCP layer). Thus, such previous works cannot indeed reduce wireless networks' energy consumption because they do not consider the interweaving of parameters deployed at different layers of the protocol stack.

II – RELATED WORK

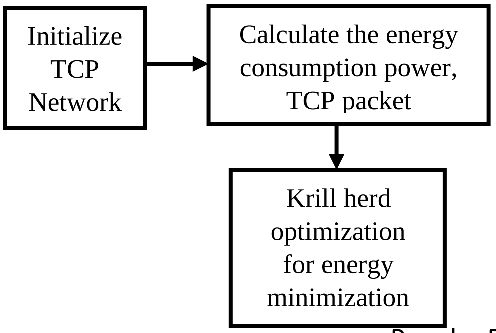
Fadlullah, et. Al., (2016) propose HetNetwork Cod- ing as a means to utilize the available radio interfaces in parallel along with network coding to increase wireless data throughput. Specifically we explore the use of random linear network coding at the network layer where packets can travel through multiple interfaces and be received via multi homing.

Cheng, et. Al., (2017 study the energy-efficient power allocation and wireless backhaul bandwidth allocation in orthogonal frequency division multiple access heterogeneous small cell networks. Different from the existing resource allocation schemes that maximize the throughput, the studied scheme maximizes energy efficiency by allocating both transmit power of each small cell base station to users and bandwidth for backhauling, according to the channel state information and the circuit power consumption.

III - SYSTEM IMPLEMENTATION

In this project, propose an energy-efficient **krill herd (KH) optimization** algorithm to solve constrained optimization problems. In this project, propose to krill herd optimization based the energy efficiency of transmitting TCP applications in a unified way. Define the energy efficiency as the ratio of TCP throughput to total power consumption and derive a mathematical expression for the energy efficiency.

To design an energy-efficient TCP transmission scheme for CRNs. In particular, we take into account spectrum sensing, spectrum access, MCS, transmission power, and TCP packet length to enhance the energy efficiency. Formulate the CRN as a POMDP system to find an optimal strategy for deploying spectrum sensing, spectrum access, MCS, transmission power, and TCP packet length. To present extensive simulation results to show that our proposed scheme can improve the energy efficiency of transmitting TCP applications in CRNs significantly.



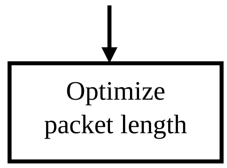


Fig .1 Block diagram

The primary work is to initiate the network parameters such as port address, server client configurations of TCP. The next important step is to start data transmission over the network. Once the data transmission is started, the energy consumed and received packet can be calculated. The Krill herd optimization is well-known algorithm for optimizing the packet length of the transmission and energy minimization.

A. TCP TRANSMISSION OVER WIRELESS NETWORKS

We consider TCP transmission in a wireless network as shown in Fig.2, where a mobile user transmits data to a video game server that connects to the base station directly via the Internet. We can see that there are one wireless link and one wireline link in this scenario.

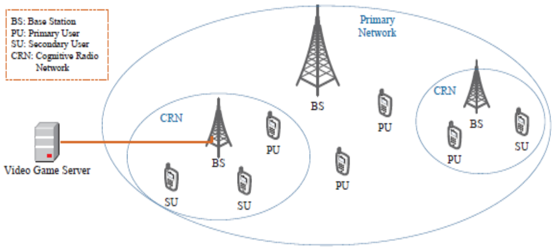


Fig.2 The considered scenario for a general cognitive radio network (CRN).

To mathematically find TCP throughput and the corresponding total energy consumption, we consider the end-to-end TCP transmission and show by Fig. 3.3 the TCP transmission from the perspective of the TCP/IP protocol stack.

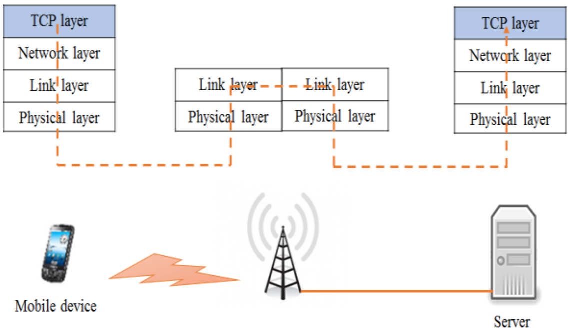


Fig.3 The end-to-end TCP transmission in a wireless network.

From this figure, we can observe the involved layers for the end-to-end communications, including the physical, link, network, and TCP layers. In the following, we describe the data at each layer.

1. The TCP layer:

The TCP layer is responsible for providing the application layer with end-to-end communications. It offers a connection-oriented, reliable communication service. The functions of this layer are to establish a TCP connection, sequence and acknowledge TCP packets, recover packet loss by employing a TCP retransmission scheme, etc.

Specifically, it employs a fast retransmission scheme where the sender retransmits a lost packet and reduces its congestion window by half after the number of received duplicated ACKs reaches a threshold. The sender retransmits a TCP packet if it does not receive an acknowledgment message within a time-out period tot. The Reno sender retransmits at most one dropped packet per round-trip time. Given the maximum retransmission times N_{ret} and the packet loss probability e_p, we can have the average number of transmitting a TCP packet in a wireless network as follows:

$$N_{av}^{tcp} = (1 - e_p^{Nret+1})/(1 - e_p) \qquad (1)$$

where N_{av}^{tcp} is the average transmission times of transmitting a TCP packet. Likewise, we can find the transmission delay of sending a TCP packet from the source node to the destination node as follows:

$$t_{av} = t_{it}\left(1 - e_p^{Nret+1}\right) + t_{ot}(e_p - e_p^{Nret+2})/(1 - e_p) \qquad (2)$$

where t_{it} is the average transmission time for a one-time IP packet transmission.

2. The network layer:

The network layer is responsible for traversing IP packets from the source node to the destination node. Logically, the network layer receives data from the TCP layer. Adding an IP header, we can encapsulate an IP packet. Let Lip and L_{iph} denote the length of an IP packet and an IP header, respectively. We can have $L_{ip} = L_{iph} + L_{tcp}$ for an IP packet. For a practical wireless network, the packet loss is mainly due to the unstable wireless environment.

Thus, the packet loss probability e_p is approximately equal to the average frame error rate, i.e.,

$$e_{p\cong}e_f^{av} \qquad (3)$$

where e_f^{av} is the average frame error rate.

Moreover, the average transmission delay of traversing an IP packet from a source node to its destination node includes two parts: the average transmission delay over a wireless link and a wireline link, respectively.

Thus, we can find the average transmission time for a one-time IP packet transmission as follows:

$$t_{it} = t_{av}^{wi} + t_{av}^{wl} \qquad (4)$$

where t_{av}^{wi} is the average transmission delay over a wireless link and t_{av}^{wl} is the average transmission delay of sending a frame over a wireline link.

3. The link-layer:

Logically, the link-layer receives data passed from the network layer, encapsulates the data into frames, and sends the frames to a receiving node. A frame is composed of a frame header, a payload, and a frame tail. The payload is an IP packet received from the network layer, and the header and tail are additional control information required by the frame layer. As a result, the frame length is $L_{fr} = Lf_{rh} + L_{ip}$, where L_{frh} is the size of the overhead.

For a wireless link, due to the bit error rate, a frame may not be sent to its receiving node successfully. Based on the wireless link's BER e_b, we can derive the frame error rate as follows:

$$e_f = 1 - (1 - e_b)^{Lfr} \qquad (5)$$

where $e_f$is the frame error rate. Researchers have so far developed many frame retransmission schemes to combat the frame error, and this paper considers a basic ARQ (automatic repeat request) scheme. Specifically, a sender retransmits a frame if it does not receive an acknowledgment message within a time-out period t_{of}.

In particular, the sender continues this retransmission process until it receives an acknowledgment or the number of retransmissions exceeds a predefined threshold N_{ref}. Hence, we can find the average frame error rate as follows:

$$e_f^{av} = e_f^{N_{ref}+1} \qquad (6)$$

Subsequently, we can find the average transmission times of transmitting a frame when employing the ARQ scheme as follows:

$$N_{avfr} = \left(1 - e_f\right)\left\{1 + 2e_f + \cdots + N_{ref}.e_f^{N_{ref}}\right\} + \left(N_{ref} + 1\right)e_f^{N_{refr}} = (1 - e_f^{N_{ref}+2})/\left(1 - e_f\right) \qquad (7)$$

Likewise, assume that the transmission delay of sending a frame over a wireless link is t_{ph}. Then, we can find the average transmission delay as follows:

$$\begin{aligned} t_{av}^{wi} &= t_{ph}\left(1 - e_f\right) + \left(t_{ph} + t_{of}\right)e_f\left(1 - e_f\right) \\ &+ \left(t_{ph} + 2t_{of}\right){e_f}^2\left(1 - e_f\right) + \cdots \\ &+ \left(t_{ph} + N_{ref}t_{of}\right){e_f}^{N_{ref}}\left(1 - e_f\right) \\ &+ \left(N_{ref} + 1\right)t_{of}e^{N_{ref}+1} \\ &= t_{ph}\left(1 - {e_f}^{N_{ref}+1}\right) + t_{of}\frac{e_f - {e_f}^{N_{ref}+2}}{1 - e_f} \end{aligned} \qquad (8)$$

On the other hand, the frame error rate is negligible when transmitting frames over a wireline link. Hence, we assume that there is no frame retransmission when sending frames over a wireline link. As a result, the average transmission delay for a frame over the wireline link is t_{ph}^l where t_{ph}^l the one-round transmission delay is spent for sending a frame.

4. The physical layer:

The physical layer is responsible for delivering bits from one sender to its receiver in communication systems. Logically, it receives frames from the link layer and adds additional controlling information to them before sending them out. As a result, we can have the number of bits to be transmitted at the physical layer as $L_{ph} = L_{fr} + L_{pc}$, where L_{pc} is the number of the additional bits.

We can notice from Fig.3 that there are two types of physical layer communications, i.e., wireless communications over a wireless link and wireline communications over a wireline link. In the following, we present them, respectively.

To enable successful physical layer communications over a wireless link, we need to deploy the right MCS and transmission power according to the wireless link quality. Based on the result in, we can obtain the BER of transmitting bits over a wireless link as follows:

$$e_b = k_1 . \exp\left(-\frac{k_2 \gamma P_{tr}}{2^{\rho}-1}\right) \quad (9)$$

where e_b is the BER, is the channel gain of the wireless link, p_{tr} is the transmission power, _ is the MCS that is determined by $\rho = \rho^{mod} . \rho^{cod}$[39] (here ρ^{mod} and ρ^{cod} are related to the modulation rate and channel code rate, respectively), and constants k1 and k2 are related to the specific constellation and code. Likewise, we can find the transmission rate by $r_{wi} = \rho^{W}$when transmitting data over the wireless link with the bandwidth W.

Subsequently, we can have the transmission delay of sending a frame over the wireless link as follows:

$$t_{ph}^{w} = L_{ph}/r_{wi} \quad (10)$$

On the other hand, to enable successful physical layer communications over a wireline link, we also need to deploy parameters at the physical layer. It is well-known that, compared to a wireless link, its bit error rate is negligible, and its bandwidth is not a limitation. Thus, we ignore the discussion of how to deploy parameters at the physical layer for wireline communications. In this paper, we assume that the transmission rate of a wireline link is rwl and the power of transmitting data over a wireline link is Pwired. We can have the transmission delay of transmitting a frame over a wireline link as follows:

$$t_{ph}^{L} = L_{ph}/r_{wl} \quad (11)$$

B. TCP Throughput and Energy Consumption

TCP throughput is widely used to characterize the steady-state performance of a TCP flow. Based on the results, we can have a simple analytical TCP throughput model as follows:

$$B(RTT, T_0, b, e_p) \approx \frac{1}{RTT . \sqrt{\frac{2be_p}{3}} + T_0 . \min\left(1, 3\sqrt{\frac{3be_p}{8}}\right) e_p (1+32{e_p}^2)} \quad (12)$$

where T0 is the initial timeout, b is the number of packets that are acknowledged by a received ACK (b is typically 2), and RTT is the RTT. RTT is the time spent for successfully sending a TCP packet from the source node to the destination node and receiving an acknowledge at the source node. Assume that the transmission time for an acknowledgment message is tack. Hence, we can find the round trip time RTT for a TCP packet as follows:

$$RTT = t_{av} + t_{ack}: \quad (13)$$

Furthermore, due to applying the sliding window mechanism, the TCP throughput is constrained by the maximum congestion window *cwnd*. Thus, we can obtain the TCP throughput B as follows:

$$B = \min\left(\frac{cwnd}{RTT}, B(RTT, T_0, b, e_p)\right) \quad (14)$$

Moreover, we also need to find the total energy consumption of transmitting a TCP packet. Specifically, for a onetime transmission over a wireless link, the power consumption is (P_{tr}+P_{rx}), where P_{rx} is the receiving power of the receiving node. Due to the retransmission at the link layer, we can have the average power consumption for transmitting data over a wireless link as follows:

$$P_{ave}^{fr} = (P_{tr} + P_{rx} + P_{dev}) . N_{av}^{fr} \quad (15)$$

where Pdev is the circuit power consumption of the devices and equipment. Subsequently, we can find the total power consumption for a one-time TCP packet transmission as follows:

$$P_{ave}^{tcp} = (P_{ave}^{fr} + P_{wired}) \quad (16)$$

Therefore, we can have total power consumption for successfully transmitting a TCP packet as follows:

$$P_{total} = P_{ave}^{tcp} . N_{av}^{tcp} \quad (17)$$

C. The Definition of Energy Efficiency

In this paper, we propose to consider the energy efficiency from the perspective of the TCP layer, instead of the physical layer. Particularly, we propose to use this metric to measure how many bits to be transmitted from a source node to a destination node when consuming one-Joule energy. To this end, we define the energy efficiency as the ratio of TCP throughput to total power consumption, i.e.,

$$EE = \frac{B}{P_{total}} \quad (18)$$

where EE denotes the energy efficiency.

We can observe that the parameters at different layers of the protocol stack interweave with each other to affect the energy efficiency EE. For example, using high-order MCS results in high data transmission rate r and low transmission delay, but high bit error rate at the physical layer and a large number of retransmissions at the link (or TCP) layer, consequently causing very low energy efficiency. Feeding high transmission power at a mobile device (or a base station) incurs high energy consumption, but a small bit error rate at the physical layer and a few retransmission times at the link (or TCP) layer, thus leading to very high energy efficiency. Transmitting large-size TCP packets over a poor wireless link (or sending small-size TCP packets over a high-quality wireless link) wastes energy because of retransmitting lost packets (or due to the deficient use of radio resources), thus incurring low energy efficiency. Therefore, we need to carefully consider the parameters deployed at every layer of the protocol stack when designing an energy-efficient TCP transmission scheme in a wireless network.

D. KRILL HERD ALGORITHM

Krill Herd algorithm is a swarm intelligence algorithm proposed for continuous optimization problems. It has been proven to have a better or comparable performance with some existing algorithmic techniques. For instance, when compared with other swarm-intelligence methods, it is easy to implement, it is robust which makes it comparable to other nature-inspired algorithms and requires few control parameters, practically, only a single parameter δt (time interval) needs to be fine-tune. In KH algorithm, the population of krills search through a multi-dimensional search space for food and the locations of krill individuals is represented as different decision variables while the distance between the krill individuals and the rich food correspond to the value of the objective cost. Note that the time-dependent location of a krill individual is measured by the three operational processes:

(i) Motion induced process,
(ii) Foraging movement and
(iii) Random physical diffusion.

Figure 4 shows the basic representation of the KH algorithm. The description and mathematical expression of these operational processes are provided in the following subsections:

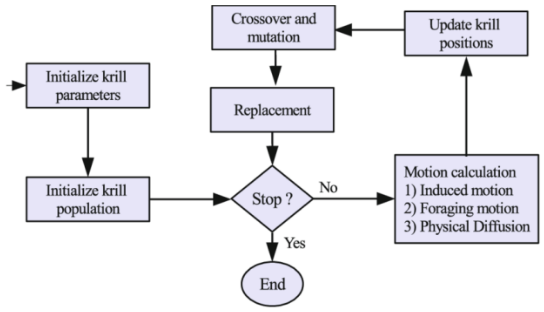


Figure 4: A flowchart of the krill herd algorithm

KHA uses the Lagrangian model to extend the search space to an n-dimensional decision space as:

$$\frac{dX_i}{dt} = N_i + F_i + D_i \qquad (1)$$

where Ni is the motion of the ith krill induced by other krill individuals, Fi represents the foraging activity, and Di denotes the physical diffusion of the krill individuals.

(1) Motion induced by other krill individuals

According to theoretical arguments, individual krill maintain a high density and move due to mutual effects. The direction of motion induced, *a*i, is estimated from the local swarm density (local effect), target swarm density (target effect), and repulsive swarm density (repulsive effect). For an individual krill, the motion can be defined as:

$$N_i^{new} = N^{max}\alpha_i + \omega_n N_i^{old} \qquad (2)$$

where:

$$\alpha_i = \alpha_i^{local} + \alpha_i^{target} \qquad (3)$$

Nmax is the maximum induced speed, *w*n is the inertia weight of the motion induced in the range [0, 1]s, Nold i is the last motion induced, *a*local i is the local effect provided by the neighbors, and *a* target i is the target direction effect provided by the best individual krill. According to the measured values of the maximum induced speed (Nmax), Nmax is taken as 0.01 (ms^{-1}).

Different strategies can be used in choosing the neighbor. Based on the actual behavior of krill individuals as shown in figure 5, a sensing distance (ds) should be determined around a krill individual and the neighbors should be found.

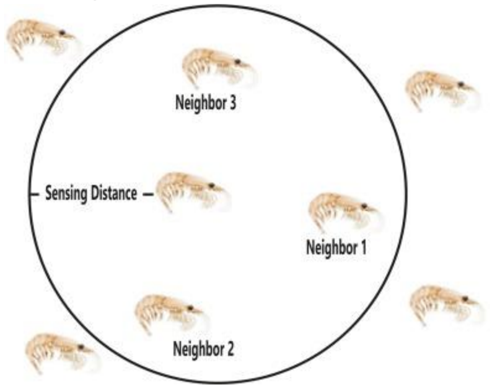


Fig 5. A schematic representation of the sensing ambit around a krill individual

The sensing distance for each krill individual can be determined by using different heuristic methods. Here, the sensing distance is determined by using the following formula for each iteration:

$$d_{s,i} = \frac{1}{5N}\sum_{j=1}^{N}\left\|X_i - X_j\right\| \qquad (4)$$

where ds,i is the sensing distance for the ith krill individual and N is the number of the krill individuals, and Xi represents the related positions of ith krill. If the distance of Xi and Xj is less than the defined sensing distance (ds,i), Xj is a neighbor of Xi.

(2) Foraging motion

This movement is intended to comply with two criteria. The first is food location, and the second is previous experience about the food location. For the ith krill, the foraging motion can be expressed as:

$$F_i = V_f \beta_i + \omega_f F_i^{old} \quad (5)$$

where:

$$\beta_i = \beta_i^{food} + \beta_i^{best} \quad (6)$$

where Vf is foraging speed, *w*f is inertia weight of the foraging motion in the range [0, 1], *b* food i is the attractive food, and *b*best i is the effect of the best fitness of the ith krill so far. According to measured values of the foraging speed, Vf is taken as 0. 02 ms^{-1}.

Food effect is defined in terms of its location. The center of food should be found and then formulated for food attraction. This solution cannot be determined, but can be estimated. In this study, the virtual center of food concentration is estimated according to the fitness distribution of krill individuals, which is inspired by the "center of mass" concept. The center of food for each iteration is formulated as:

$$X^{food} = \frac{\sum_{i=1}^{N} \frac{1}{K_i} X_i}{\sum_{1=i}^{N} \frac{1}{K_i}} \quad (7)$$

where Ki is the objective function value of the ith krill individual.

(3) Physical diffusion

The physical diffusion of the krill individuals is considered a random process. This motion can be expressed in terms of a maximum diffusion speed and a random directional vector. The formula is as follows:

$$D_i = D^{max}(1 - \frac{I}{I_{max}})\delta \quad (8)$$

where Dmax is the maximum diffusion speed, and *d* is the random directional vector and its arrays are random values between □1 and 1. I is the actual iteration number and Imax is the maximum number of iterations.

(4) Motion process of KHA

Defined motions regularly change the krill position toward the best fitness. The foraging motion and motion induced by other krill individuals contain two local (*a*local i , *b*best i) and two global strategies (*a* target i , *b* food i), which work simultaneously and create a powerful algorithm. Using diverse operative parameters of the motion throughout the time, the position vector of a krill individual during interval t to t + Dt is expressed by the following equation:

$$X_i(t + \Delta t) = X_i(t) + \Delta t \frac{dX_i}{dt} \quad (9)$$

where Xi(t + Dt) represents the updated krill individual position, and Xi(t) represents the current position. Note that Dt is considered the most important constant and should be tuned carefully based on the optimization problem. This is because this parameter works as a scale factor of the speed vector, and Dt can be obtained from the following formula:

$$\Delta t = C_t \sum_{j=1}^{NV} (UB_j - LB_j) \quad (10)$$

where NV is the total number of variables, and LBj and UBj are the lower and upper bounds of the jth variables (j = (1, 2, . . . , NV)), respectively. Therefore, the absolute of their subtraction shows the search space. It is empirically found that Ct is a constant number between [0, 2]. It is also obvious that low values of Ct let the krill individuals search the space carefully.

(5) Genetic operators

Crossover operation is the use of a binomial crossover scheme to update the mth components of the ith krill by the following formula:

$$X_{i,m} = \begin{cases} X_{r,m} \; rand_{i,m} < C_r \\ X_{i,m} \quad\quad else \end{cases} \quad (11)$$

$$Cr = 0.2\hat{K}i, best \quad (12)$$

where Cr is crossover probability, which is a random number between 0 and 1, r ε {1, 2, . . . , i - 1, i + 1, . . . , N}. Mutation is controlled by mutation probability (Mu). The adaptive mutation scheme used is formulated as

$$X_{i,m} = \begin{cases} X_{gbest,m} + \mu(X_{p,m} - X_{q,m}) \; rand_{i,m} < Mu \\ X_{i,m} \quad\quad else \end{cases} \quad (13)$$

$$Mu = 0.05/\hat{K}i, best \quad (14)$$

where p, q ε {1, 2, . . . , i - 1, i + 1, . . . , N} and *m* is a number between 0 and 1. In ˆKi,best , the nominator is Ki - Kbest. Based on this new mutation probability, the mutation probability for the global best is equal to zero, which increases as fitness decreases.

IV - SIMULATION RESULTS

The initial network design is shown in the following figure.6. Where the active nodes are having their spatial coordinates and the cluster head is having a specific center location. The cluster is working as a sink node which is acting as a base station.

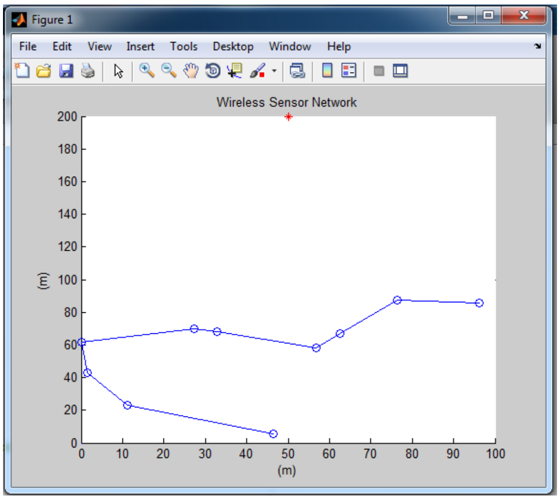


Fig.6 Node initialization

The implementation of krill herd (KH) optimization is actively minimizing the energy loss during the transmission period. The following figure 7 & 8 shows KHO implementation.

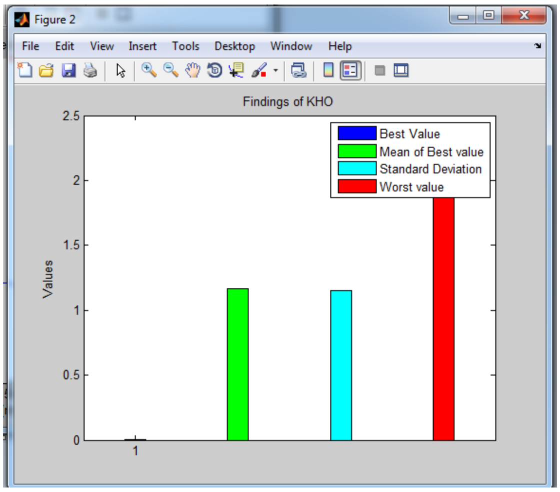


Fig.7 Finding of KHO

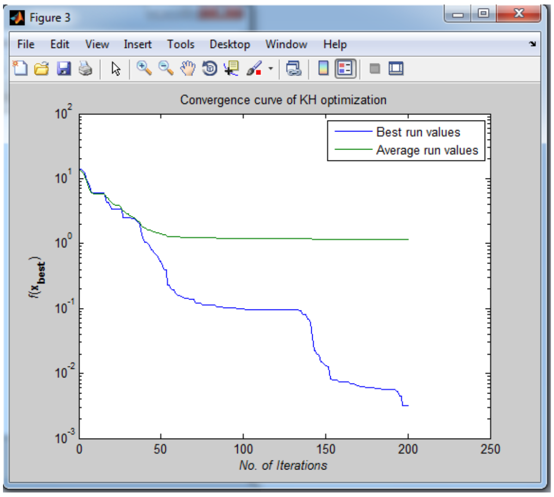


Fig.8 Optimization of energy using KHO

The energy of the node during the transmission of data is maintained as a constant which is indeed for improving the efficiency of the data transmission. It is shown in the following figure.9 where the node energy is the same for all the transmission.

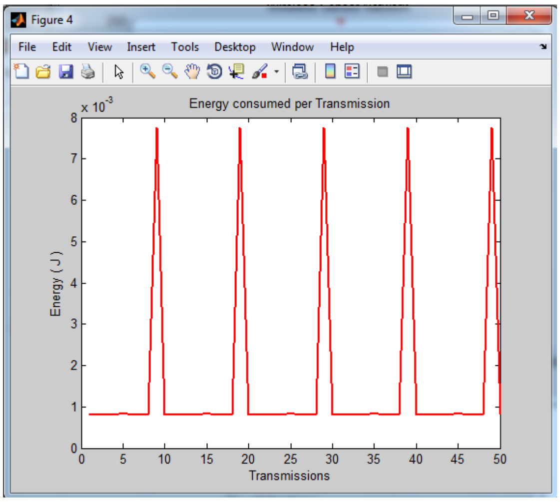


Fig.9 Energy consumed per Transmission

The average energy of the node is found as 1.9J which is not even dropped during the whole process.

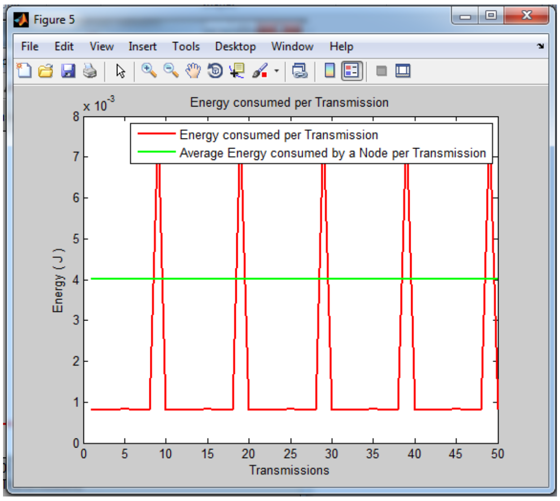


Fig.10 Average energy consumed by a Node per Transmission

The energy efficiency curve of KHO is shown in fig 11. This is compared with existing GWO and proposed KNO. The energy efficiency after implementing KHO is comparatively high it is shown in the following figure.12

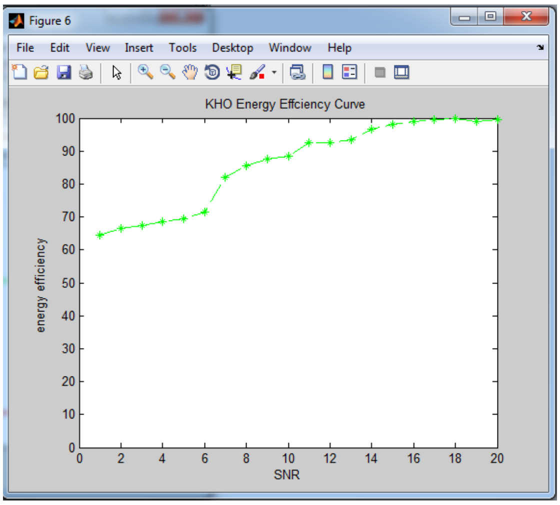


Fig.11 Energy Efficiency

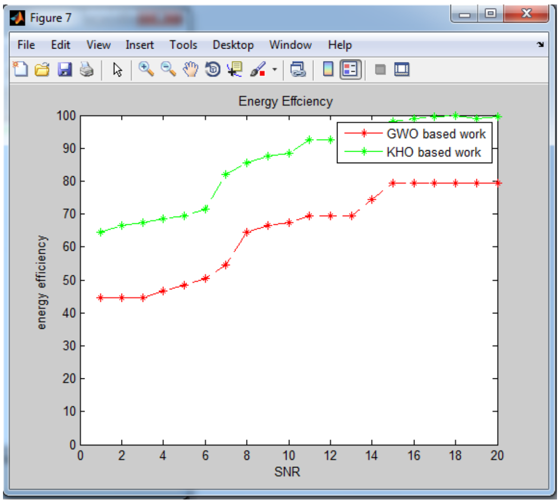


Fig.12 Comparison of Energy Efficiency with KHO and GWO

V - CONCLUSION

In this project, we have studied the problem of energy efficient TCP transmission in CRNs. To improve energy efficiency, we consider optimizing energy consumption in a unified way. Specifically, we have proposed to enhance energy efficiency from the perspective of the TCP layer and defined it as the ratio of TCP throughput to total power consumption. Particularly, we have derived a mathematical expression of the energy efficiency by considering TCP transmission in a wireless network. Then, we have designed an energy-efficient Krill Herd Algorithm based TCP transmission scheme for transmitting TCP applications in CRNs. In particular, we jointly take into account spectrum sensing, spectrum band access, MCS, transmission power, and TCP packet length in this scheme. To validate our proposed scheme, we have provided extensive simulation results to show the significant performance improvement in energy efficiency.

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