Sperm Swarm Optimization Algorithm for Optimizing Wireless Sensor Network Challenges

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ABSTRACT
This paper proposes a new meta-heuristic optimization approach, called "Sperm Swarm Optimization (SSO)". The underlying ideas and concepts behind the proposed method are inspired by sperm motility to fertilize the egg. In SSO, sperm swarm moves forward from a low-temperature zone called Cervix. During this direction, sperm searches for a high-temperature zone called Fallopian Tubes where the egg is waiting for the swarm for fertilization in this zone, which this area is considered as the optimal solution. The SSO is tested with optimizing several objective functions that represent Wireless Sensor Network (WSN) quality of services, which is used to minimize both the end-to-end delay and end-to-end latency and also to maximize both the packet throughput and energy efficiency.

CCS Concepts
Theory of computation~Theory of randomized search heuristics

Keywords
Sperm Swarm Optimization (SSO); Meta-heuristics; Wireless Sensor Network (WSN); Quality of Services (QoS).

1. INTRODUCTION
In order to achieve an accurate solution for large-scale real-life problems, different types of heuristics based algorithms have been proposed. However, exact optimization approaches are not efficient enough to find an accurate solution for problems with high dimensional search space domain. Therefore, to overcome these problems, different optimization approaches have been developed, most of them created based on a metaphor of some manmade or natural procedures. The main aim is to find a good solution that is optimal or near to the optimal solution.

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Example of well-known meta-heuristic optimization approaches are Simulated Annealing [1], Genetic Algorithm [2], Particle Swarm Optimization [3], and Ant Colony Search Algorithm [4]. These algorithms have been playing a significant role in optimizing various kinds of real-life problem such as WSN challenges and problems. WSN has been experiencing extremely fast growth in fields of sensing and monitoring. However, WSN faces many challenges such as energy management [5], delay of data aggregation [6], security issues [7], etc. In addition, WSN consists of different kinds of tiny sensors, which have limited capabilities such as limited space in memory [8], limited ranges of communication, and limited power in the sensors batteries [9]. The misuse of these sensors leads to reduce QoS and lifetime of the network [10].

The previously mentioned algorithms are used to solve different kinds of problems. However, they suffer from the main shortcoming, i.e. being stuck in local minima and they have low convergence in high dimensional search space. For this reason and to overcome this challenge, many other optimization algorithms have been developed. Examples of these algorithms are Cuckoo Optimization Algorithm (COA) [11], and Gravitational Search Algorithm (GSA) [12]. These algorithms are very complex, which are very difficult to use. The evaluation of these algorithms based on the interaction of various parameters and components. These parameters are stochastic, complex, and highly nonlinear. WSN is challenging, which include highly nonlinear constraints, objective functions, and a large number of variables. These problems are considered as NP-hard in nature. The complexity and size of the problems nowadays require the proposing of highly efficient techniques. This work is organized as follows: Section 2 provides a brief review of fertilization procedure. Section 3 presents the ideas and concepts behind SSO in details. In Section 4 the experimental results are demonstrated. Finally, conclusions are given in Section 5.

2. FERTILIZATION PROCEDURE
Fertilization procedure is the epic story of a single sperm acting and facing incredible odds to unite with an egg (Ovum). There are over than 130 million sperm cells compete to fertilize one egg, hence, in normal status, there is one and only one sperm will fertilize the egg. In this section, we summarize the procedure that happened inside the female reproductive system and we simulate it as an algorithm. The following steps summarize the fertilization procedure.

The swarms of sperm are triggered by male reproductive system inside the cervix, which is the first step of fertilization procedure. In this step, each sperm takes a random position inside the cervix to prepare itself for the fertilization journey, where each sperm has two velocities on X-axis and on Y-axis. We can denote the sperm velocities as (Vsx[], Vsy[]).

After that, the sperm swarms are ready to swim forward from cervix until reaching the egg, which is located inside the Fallopian Tubes. Researchers found that the sperm swarms move together forming groups when they are swimming in viscoelastic fluids and their behavior of moving exhibiting similar to “flocking”. They also observed a certain movement beat and degree of synchronicity of tail movements during grouping [13].

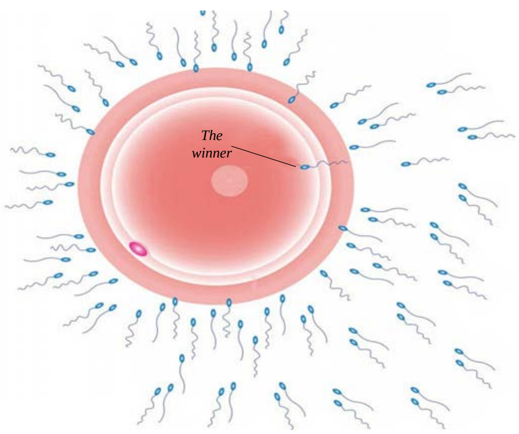

Figure 1. The winner and other sperms reach the egg

After insemination, the sperm will travel through the Fallopian Tubes. If ovulation has occurred, the egg will release a chemical that attracts the sperm. This procedure is called *Chemotactic*. Scientists believe that sperm finds a waiting egg cell via a couple of complex mechanisms. Sperm swims toward the high-temperature areas of the woman’s reproductive tract, where *Ovums* (eggs) are found. This behavior of sperm is called *Thermotaxis*. They found that sperm prefers to swim towards warmer temperatures. Sperm can response and sense to a temperature difference of <0.0006°C. Furthermore, they found that sperm moves forward searching on the guidance (higher concentrations of molecules) that produced and released by the egg, which this guidance is known as *Chemo-taxis* [14, 15]. From this information, we can realize that sperm will not swim backward to the cervix, but, will go forward towards warmer temperatures (the egg location). Sperm swarms change their velocity and compete with each other as rally competition until they reach the egg. The first sperm reaches the egg will use an enzyme produced inside its acrosomes to make an opening in the membrane of the egg. This sperm is considered as the winner because it enters the egg where only the head enters, after that, the egg orders a membrane to prevent other sperm from entering. This simulates the best solution by any sperm has achieved so far remarked by the winner. Figure 1 shows the winner and other sperm cells reach the egg, while Figure 2 summarizes the fertilization procedure [16] inside the female reproductive system.

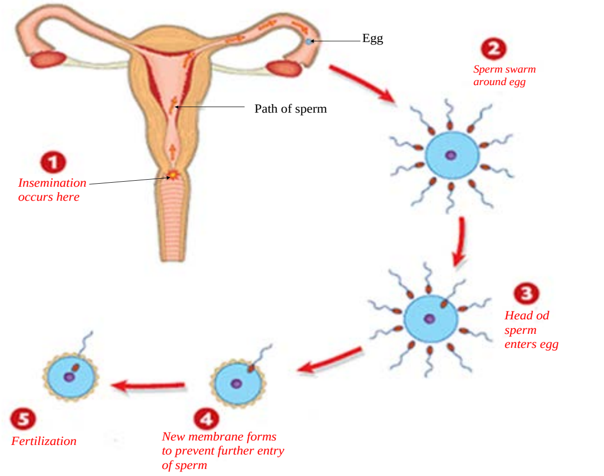

Figure 2. The fertilization procedure [16]

3. SPERM SWARM OPTIMIZATION ALGORITHM

In this section, we simulate the fertilization procedure as an algorithm. For this reason, we are going to summarize the limitations on sperm movement in the following points:

(1) The pH value inside the female reproductive system is around 4.5–5.5 [17], which are represented as normal pH values for a healthy vagina. However, sperm does not like low pH values, for that reason, in the time of ovulation, the pH of vaginal acid or acidic is anywhere stable in the range of 7 to 14, which is very appropriate for sperm motility and is considered very alkaline and non- toxic to sperm [18]. In other words, low pH of mucus acidic may deactivate the motility of sperm and destroy sperm. The pH value of the female reproductive system is affected by the type of food consumed [19] and mood status or emotional of the female, such as happiness or sadness, etc. [20]. Based on this information, we can estimate that the value of pH will be varied in the range of 7 to 14.

(2) As we mentioned previously, sperm head acts like temperature sensor, which searches on the warmer area (the egg location). The temperature inside the vagina can be changed based on women status. The researchers found that the temperature average inside the vagina approximately from 35.1 to 37.4 in degrees Celsius [21]. However, this temperature may increase until reach 38.5 degrees Celsius in some cases due to vaginal blood pressure circulation [22]. Based on this information, we can estimate that the value of temperature will be varies in the range of 35.1 to 38.5.

Based on the previous information, we can notice that sperm velocity is affected by the pH value and the temperature inside the vagina, which play a significant role in sperm motility and its movement direction. We can summarize the velocity of sperm in the following steps:

Initial velocity is the velocity that sperm acquired after the ejaculation in cervix zone. The sperm swarms take random positions inside the cervix and their velocity is affected by the pH value in that position. We can express the initial velocity by the following equation:

$$Initial\_Velocity = D \cdot V_i \cdot Log_{10}(pH\_Rand_1) \quad (1)$$

Where:

- D is a velocity damping factor, which is random number between 0 and 1. This factor is used to adjust the sperm velocity.
- V_i is the sperm velocity,
- pH_Rand_1: is a random number in the range from 7 to 14, which represents the pH value.

Personal sperm current best solution is the best solution that has been achieved so far by the sperm. This position can be achieved by comparing the sperm current position on X-axis and Y-axis with a sperm past position that is stored in the memory. The past position can be replaced by current position, just in case of if the current position is better than the past position. We can express the personal sperm current best solution in the following equation:

$$Current\_Best\_Solution = Log_{10}(pH\_Rand_2) \cdot Log_{10}(Temp\_Rand_1) \cdot (sb\_solution[] - current[]) \quad (2)$$

Where:

- sb_ solution [] is the best solution it has achieved so far, which denoted by to Sperm Best (*sb_ solution*),
- pH_Rand_2 is a random number in the range from 7 to 14, which represents the pH value,
- $Temp\_Rand_1$ is a random number in the range from 35.1 to 38.5, which represents the area temperature.

Global best value indicates, which sperm's data is currently closest to the target (at the end, this sperm will represent as the winner). The value of sperm global best value is represented by the following equation:

$$Global\_Best\_Solution = Log_{10}(pH\_Rand_3) \cdot Log_{10}(Temp\_Rand_2) \cdot (sgb\_solution[] - current[]) \quad (3)$$

Where:

- sgb_solution[] is the best solution which any sperm has achieved so far which denoted by Sperm Global Best (*sgb_solution*),
- pH_Rand_3 is a random number in the range from 7 to 14, which represents the pH value,
- $Temp\_Rand_2$ is a random number in the range from 35.1 to 38.5, which represents the area temperature,
- current [] is the current best solution which is represented by the following equation.

$$current[] = current[] + v[] \quad (4)$$

Where v [] is the sperm velocity which can be measured by using equation (5).

$$v[] = Initial\_Velocity + Current\_Best\_Solution + Global\_Best\_Solution \quad (5)$$

We can represent the sperm velocity update rule as Equation (5). This rule represents three different velocities that are used by each sperm to reach the optimal solution (the location of the egg), we can summarize these velocities as the following steps. The first velocity is the initial velocity of sperm, which is acquired after the ejaculation in cervix zone. This velocity is affected by the value of pH in the cervix zone. The second velocity is personal sperm current best solution, which is recorded by the best solution found by the sperm itself. This velocity is affected by two factors, including, the value of pH and temperature of the visited zone, which zone temperature helps the sperm to know the egg location. The third velocity is the sperm global best value, which is recorded by the swarm based on the winner solution. As we mentioned previously, there is only one sperm that will fertilize the egg because its solution is the closest to the target. This velocity is affected by two factors, including, the value of pH and temperature of the visited zone. The temperature is a very important factor, which helps the sperm to know the egg location.

From the previous models, we can create a full Sperm Swarm Optimization (SSO) algorithm as follows.

Algorithm 1 *Sperm Swarm Optimization (SSO)*
Begin
Step 1: initialize positions for all sperms.
Step 2: ***for*** *i=1:population size* ***do***
Step 3: *Evaluate the fitness for each sperm*
    if *obtained fitness > sperm best solution* ***then***
    set the current value as the sperm best solution
    end if
  end for
Step 4: *choose the sperm global best solution based on the winner.*
Step 5: ***for*** *i=1: population size* ***do***
    Do the swim using velocity update rule
    update sperm location on the search space
  end for
Step 6: ***for*** *i=1:population size* ***do***
    if (i % 3 == 0) then
    sperms mutated with a non-uniform mutation operator
    else if (i % 3 == 1)
    sperms mutated with a uniform mutation operator
    else
    sperms without mutation
    end if
    end for
Step 7: ***while*** *maximum iterations are not achieved* ***return to step 2*** *and* ***repeat*** *until reaching the maximum iteration.*
End.

In order to enhance the SSO algorithm performance and convergence, we divide the population size into three equal parts by taking the modulus (mod) of sperm index (population index) on the value of three. In the first part of the population, we perform the non-uniform mutation operator, in the second part, we perform a uniform mutation operator. On the other hand, in the third part, we do not perform mutation. This helps to increase the convergence of the algorithm and in case if the mutation operators do not give good results, the third part of the population (population without mutation) will reserve good results.

4. EXPERIMENTAL RESULTS

To validate the performance of the introduced method, SSO is applied to optimize a set of metrics related to WSN QoS. We can represent these functions at the following points:

4.1 End-to-End Delay Model

End-to-end delay (T_l) is considered as an important model of WSN, which in case it decreases the network QoS will be increased. This function can be summarized by the following equation [23]:

$$T_l = T_{packet} + T_{IFS} + T_{bo} + T_{TA} + T_{ACK} \tag{6}$$

Where

- T_{packet} is transmission time of packet;
- T_{IFS} is inter-frame space-time;
- T_{bo} is backoff time;
- T_{TA} is a turnaround time of transceivers;
- T_{ACK} is an acknowledgment of receipt time.

The T_{packet} is used to measure the time that is needed by any packet until reaching the destination in a successful way. T_{packet} can be expressed as follows:

$$T_{packet} = \frac{L_{PHY} + L_{MHR} + payload + L_{MFR}}{R_{data}} \tag{7}$$

Where:

- R_{data} is the data transmission rate;
- L_{MFR} is size of MAC footer in byte;
- Payload is size of data in the packet in byte;
- L_{MHR} is size of MAC header in byte;
- L_{PHY} is size of the physical header in byte.

Now, the backoff periods model can be defined as follows. This model is used to determine the probability of any node to access the channel.

$$P_S = \sum_{a=1}^{a=b} P_C(1\text{-}P_C)^{(a\text{-}1)} \tag{8}$$

Where

- b is the maximum number of backoff periods;
- P_c is the assessment probability of the ideal channel that can be measured by any node. p_c can be measured as follows:

$$P_c = (1\text{-}q)^{n\text{-}1} \tag{9}$$

Where q is the probability of node transmit at any time, and n is the number of nodes. The average of backoff periods (R) can be measured by:

$$R = (1\text{-}P_S)b + \sum_{a=1}^{a=b} aP_C(1\text{-}P_C)^{(a\text{-}1)} \tag{10}$$

Therefore, the T_{bo} (total of backoff time), which can be expressed as:

$$T_{bo} = FractionalPart[R]T_{bop}(IntegerPart[R]+1) + \sum_{a=1}^{a=IntegerPart[R]} T_{bop}(a) \tag{11}$$

Where average backoff period (T_{bop}) can be measured by:

$$T_{bop(a)} = \frac{2^{macMinBe+a-1}-1}{R_{data}} T_{boslot} \tag{12}$$

Where macMinBE is the initial value of backoff and Tboslot is the backoff time at one slot duration. For ZigBee/ IEEE 802.15.4, one slot duration equal to the duration of twenty symbols.

4.2 End-to-End Latency Model

This model is used to measure the time between the process of packetizing the sensed data and the time that need until transmitting these data, after that, coordinator receives these data refers to end-to-end latency (*Te)* [24]. *Te* can be measured as follows:

$$Te = T_{sam} + T_l \tag{13}$$

Where T_{sam} is sampling time and T_l is the end-to-end delay. The T_{sam} can be measured as follows:

$$T_{sam} = \frac{payload}{Sampling\ rate\ .} \tag{14}$$

4.3 Energy Efficiency Model

This model is used to measure the efficiency of the network, which is a maximization model. The energy efficiency model (η) can be expressed as follows [10]:

$$\eta = \frac{E_c \cdot payload}{E_c \cdot (payload + h_{(L_{MHR}+L_{MAC})}) + E_s} \cdot (1 - PER) \tag{15}$$

where

- E_c is the energy consumption through the communication;
- E_s is the energy consumption in start-up mode;
- Payload is the size of data in the packet in byte;
- $h(L_{MHR}+L_{MAC})$ is the packet header length, which is the summation of both L_{PHY} and L_{MHR}. L_{PHY} is the size of physical header in byte while L_{MHR} is the size of MAC header in byte;
- PER is the Packet Error Rate.

4.4 Network Throughput Model

This model also is used to measure the efficiency of the network, which is a maximization model. The throughput model (u_{tput}) can be expressed as follows [10]:

$$u_{tput} = \frac{Payload \cdot (1 - PER)}{T_{flow}} \tag{16}$$

Where

- Payload is packet payload size,

- T_{flow} is the transmission latency,
- PER is the packet error rate and it can be measured by the following equation [25]:

$$PER = 1 - (1 - BER)^{(Length-of-packet-in-bits)} \tag{17}$$

Where BER is the bit error rate.
We have assumed a network topology 50×50 meters contains 5 sensors deployed as a grid for monitoring. Figure 3 shows the network topology, which all the nodes connected using star topology with a coordinator node (node number 3). We implement SSO algorithm in the JMetal 4.5 tool. This tool is compiled in NetBeans IDE 8.0.2 by using Java version.We use SSO algorithm to minimize both the end-to-end delay and end-to-end latency and also to maximize both the packet throughput and energy efficiency. We have used standard simulation parameters. These parameters are summarized in Table 1. These parameters are assigned based on parameters in [26, 27, 28]. The maximum packet payload size that supported by ZigBee is 114 bytes [10]. The parameters of SSO algorithm are including, a number of iterations equal to 100, and number of sperms in the swarm equal to 20.

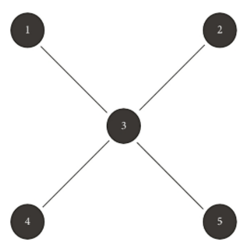

Figure 3. Network topology

Table 2 shows the results of minimizing both the end-to-end delay and end-to-end latency and also maximizing both the packet throughput and energy efficiency. These results illustrated by average, median, worst and best value of each objective function.

Table 1. Simulation parameters

Parameter	**values**
Sampling rate	250 Hz
Time of interframe space (T_{ifs})	192 µ*s*
Transceiver's transmitting to receiving turnaround time (T_{TA})	192 µ*s*
The duration of one backoff slot (*Tboslot*)	320 µ*s*
Use of ACKs	N0
PHY header (*LPHY*)	6 bytes
MAC header (*LMHR*)	11 bytes
MAC footer (*LMFR*)	2 bytes
The default minimum value *of* backoff exponent (*macMinBE*)	3
The default maximum value *of* backoff exponent (*aMaxBE*)	5
Number of sensors (*n*)	5
Transceiver's raw data rate (R_{data})	250 kbps
The energy consumption in startup mode (E_s)	8 mA
Energy consumption through the communication (E_c)	19.7 mA
Bit Error Rate (BER)	*4x10 ^ - 4*

Table 2. Results of minimizing both the end-to-end delay and end-to-end latency and also maximizing both the packet throughput and energy efficiency

Metrics	**Results of SSO method**			
	Worst	**Best**	**Average**	**Median**
End-to-end delay (ms)	1.4936	0.240464	0.597955	0.253272
End-to-end latency (ms)	15.6305	0.279628	2.824209	0.383203
Packet throughput (kbps)	0.010401	3.1617	1.440181	1.24592
Energy efficiency	0.09634	0.602211	0.408912	0.547037

According to experimental results of SSO shows a great performance in solving some benchmark functions in the area of WSN. In general, the results show the high performance of SSO, which give good results for the proposed models.

5. CONCLUSION

In this paper, SSO algorithm is proposed as a new nature-inspired algorithm to tackle different types of optimization problems. The underlying ideas and concepts behind SSO are based on the sperm fertilization procedure.

In SSO, sperm moves forward from a low-temperature zone called Cervix. During this direction, sperm searches for a high-temperature zone called Fallopian Tubes. The zone of Fallopian Tubes is considered as optimal value, which the egg located in this area waiting for sperms.

To prove its performance, SSO is tested with several benchmark functions in the area of WSN, which is used to minimize both the end-to-end delay and end-to-end latency and also to maximize both the packet throughput and energy efficiency. The results show that SSO obtained a good average results of the proposed models, which obtained a value of 0.597955 ms for the average end-to-end delay, 2.824209 ms for the average end-to-end latency, 1.440181 kbps for average packet throughput, and 0.408912 of average energy efficiency. In future works, we will compere SSO with different types of algorithms in the area of optimization such as Particle Swarm Optimization (PSO) and Genetic Algorithm (GA).

6. AUTHORS' CONTRIBUTIONS

The work was deduced from Hisham's Ph.D. thesis as Dr. Mohd Yamani Idna Idris and Dr. Ismail Ahmedy supervised him along his study.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] Kirkpatrick, S. Gelatt, C. D., and Vecchi, M. P. 1987. Optimization by simulated annealing. *Readings in Computer Vision*, 220, 4598 (May1987), 606–615. DOI= https://doi.org/10.1016/B978-0-08-051581-6.50059-3

[2] Holland, J. H. 1975. *Adaptation in Natural and Artificial Systems*. Ann Arbor, MI: University of Michigan Press.

[3] Kennedy, J., and Eberhart, R. 1995. Particle swarm optimization. *In IEEE International Conference on Neural Networks*, (Perth, Western Australia, 27 November-1 December, 1995)., 1942–1948. DOI= https://doi.org/10.1109/icnn.1995.488968

[4] Dorigo, M., Maniezzo, V., and Colorni, A. 1996. Ant system: optimization by a colony of cooperating agents. *IEEE Trans. Syst. Man Cybern. Part B Cybern*., 26, 1 (May. 1996), 29–41. DOI= https://doi.org/10.1109/3477.484436

[5] Yassein, M. B., Hamdan, M., Shehadeh, H. A. 2017. Mrayan, L. A Novel approach for health monitoring system using wireless sensor network. *International Journal on Communications Antenna and Propagation (IRECAP)* 2017, 7, 4 (Aug. 2017) 271-285. DOI=https://doi.org/10.15866/irecap.v7i4.11311.

[6] Yan, X., Du, H., Ye, Q., Song, G. 2016. Minimum-delay data aggregation schedule in duty-cycled sensor networks. *In International Conference on Wireless Algorithms, Systems, and Applications, Springer International Publishing*, (Bozeman, Montana, USA, 8-10 August 2016), 305-317. DOI=https://doi.org/10.1007/978-3-319-42836-9_28 .

[7] Rajput, M., and Ghawte, U. 2017. Security challenges in wireless sensor networks. *International Journal of Computer Applications*, 168, (Jun. 2017) 24-29, DOI= https://doi.org/10.5120/ijca2017914414 .

[8] Singh, R., Singh, J., Singh, R. 2016. Security challenges in wireless sensor networks. *International Journal of Computer Science and Information Technology & Security (IJCSITS)*, 6,2 (May. 2016), 1-6. https://ijcsits.org/papers/vol6no32016/1vol6no3.pdf

[9] Yassein, M. B., Hamdan, M., and Shehadeh, H. A. 2016. Performance evaluation of health monitoring network for elderly patient in home. *Asian Journal of Mathematics and Computer Research*, 9,2 (Jan. 2016) 108-118, DOI= http://www.ikpress.org/abstract/4914.

[10] Hamdan, M., Yassein, M. B., and Shehadeh, H. A. 2015. Multi-objective optimization modeling of interference in home health care sensors. In *Innovations in Information Technology (IIT), 2015 11th International Conference on,* (Dubai, UAE, 1-3 November 2015), 219-224. DOI= https://doi.org/10.1109/innovations.2015.7381543

[11] Rajabioun, R. 2011. Cuckoo optimization algorithm. *Appl. Soft Comput*., 11, 8 (Dec. 2011), 5508–5518. DOI= https://doi.org/10.1016/j.asoc.2011.05.008

[12] Rashedi, E., Nezamabadi-pour, H., and Saryazdi, S. 2009. GSA: A Gravitational search algorithm. *Inf. Sci.,* 179, 13 (Jun. 2009), 2232–2248. Google Scholar

[13] Tung, C. K., Fiore, A. G., Ardon, F., Suarez, S. S., and Wu, M. 2015. Collective dynamics of sperm in viscoelastic fluid. *In APS Meeting Abstracts*, 1, 1(Feb.2015)10-30. DOI= https://doi.org/10.1134/s0015462813010110

[14] Bahat, A., Caplan S., and Eisenbach, M. 2012. Thermotaxis of human sperm cells in extraordinarily shallow temperature gradients over a wide range. *PloS one*, 7, 7 (Jul. 2012), 41-59. DOI= https://doi.org/10.1371/journal.pone.0041915

[15] Bahat A., and Eisenbach, M. 2006. Sperm thermotaxis. *Molecular and Cellular Endocrinology*, 252, 1 (Jun.2006),115-119. DOI= https://doi.org/10.1016/j.mce.2006.03.027

[16] Carlso, B. M. (2012). *Human Embryology and Developmental Biology.* Elsevier Health Sciences.

[17] Neves, D., and Bahia, M. (2006). Gels as vaginal drug delivery systems. *International Journal of Pharmaceutics*, 318, 1 (Aug. 2006), 1-14. DOI= https://doi.org/10.1016/j.ijpharm.2006.03.012

[18] Rodrigues, J., Caldeira, J., and Vaidya, B. 2009. A novel intra-body sensor for vaginal temperature monitoring. *Sensors*, 9, 4 (2009), 2797-2808. DOI= https://doi.org/10.3390/s90402797

[19] Borges, S.F., Silva, J.G., and Teixeira, P.C., 2011. Survival and biofilm formation of Listeria monocytogenes in simulated vaginal fluid: Influence of pH and strain origin. *FEMS Immunol. Med. Microbiol*., 62, 3 (Aug. 2011), 315–320. DOI= https://doi.org/10.1111/j.1574-695x.2011.00815.x

[20] Edmunds, M.W., and Mayhew, M.S. 2013. *Pharmacology for the Primary Care Provider-E-Book*. Elsevier Health Sciences: Washington, DC, USA.

[21] Christian Nicole. 2013. Available online: https://christiannicole72838.wordpress.com/2013/06/26/from-the-figure-for-women-to-understand-their-own-sexual-organs-gender/ (accessed on 21 September 2017).

[22] Health. 2011. Available online: http://health-of-people.blogspot.com/2011/03/interestingly-statistics-of-physical.html (accessed on 28 September 2017).

[23] Ahmedy, I., Shehadeh, H. A., and Idris, M. Y. I. 2017. An estimation of QoS for classified based approach and nonclassified based approach of wireless agriculture monitoring network using a network model. *Wireless Communications and Mobile Computing* 2017, (Jul. 2017), 1-14. DOI= https://doi.org/10.1155/2017/3626571

[24] Liang, X., and Balasingham, I. 2007. Performance analysis of the IEEE 802.15. 4 based ECG monitoring network. In *Proceedings of the 7th IASTED International Conferences on Wireless and Optical Communications*, (Montreal, Quebec, Canada, May 30 – June 1, 2007), 99-104. DOI= https://doi.org/10.5120/13302-0838

[25] Ganhão, F., Vieira, J., Bernardo, L., and Dinis, R. 2013. Type II Hybrid-ARQ for DS-CDMA: A Discrete Time Markov Chain Wireless MAC Model. In *Internet of Things,*

Smart Spaces, and Next Generation Networking, 1st ed.; Balandin, S., Andreev, S., and Koucheryavy, Y. (Eds.), Heidelberg, Germany, 1, 1 (Jun. 2013) 176-187. DOI= https://doi.org/10.1007/978-3-642-40316-3_16

[26] Datasheet, M. 2006. MICAz, *Wireless Measurement System*. San Jose, California, USA: Crossbow technology inc.

[27] Bhuiyan, M. Z. A., Wu, J., Wang, G., Wang, T., and Hassan, M. M. 2017. E-sampling: event-sensitive autonomous adaptive sensing and low-cost monitoring in networked sensing systems. *ACM Transactions on Autonomous and Adaptive Systems (TAAS)*, *12*, 2 (Mar. 2017) 1-29. DOI=https://doi.org/10.1145/2994150

[28] Saadon, E. I. S., Abdullah, J., and Ismail, N. 2013. Evaluating the IEEE 802.15. 4a UWB physical layer for WSN applications. *In IEEE IEEE Symposium on Wireless Technology and Applications (ISWTA)*, (Kuching, Malaysia, 22-25 September 2013), pp. 68-73, DOI=https://doi.org/10.1109/iswta.2013.6688819.