2017 IEEE International Conference on Technological Innovations in ICT For Agriculture and Rural Development (TIAR 2017)

Statistical Analysis and Modeling of Honeybee Foraging Networks for Apiculture

Sudhir K. Routray, Renny M. Thakeran, D. N. Srikanth, P. Preeti and K. Keerthi
Department of Telecommunication Engineering
CMR Institute of Technology, ITPL Road
Bangalore, India
{sudhirkumar.r, than11te, srdn12tc, prit11te, keer12tc}@cmrit.ac.in

***Abstract*—Foraging is a typical behavior of honeybees. In fact, it is the main purpose of the lives of the working class honeybees. Foraging is essential for the survival of the honeybees and it has significant impact on the pollination of grains in the foraging environment. In order to have proper pollination as well as healthy production of honey, it is necessary to have an optimized environment of foraging. In this article, we provide the study and analysis of honeybee foraging networks. The main aim of this work is to develop a statistical model for honeybee foraging network distances as measured from the beehives. This can be a potential application in improving the yield in apiculture (cultivation of honeybees). We develop a statistical model for honeybee foraging networks in the similar way they are modeled for communication networks. At present, there is no statistical model available for honeybee foraging network distances. This statistical model for honeybee foraging networks can help the apiculture farmers to improve their yield. From our analysis, we find that GEV distribution is suitable for the statistical modeling of honeybee foraging networks.**

Keywords—Honeybee foraging; foraging network; statistical model for foraging network; apiculture; GEV model for foraging networks

I. INTRODUCTION

Honeybees are social animals and they live together in a hive. The worker bees collect the forage and pollens for their hives. Now, it is known that honeybees are not doorstep foragers. Rather they go some distances to gather their forage. It is also true that majority of the bees do not go very far from the hive to collect forage and pollens. That is why, it is not clearly understood how the honeybees foraging distances are distributed. The knowledge of these distances or at least their distribution can provide a lot of information on forage collections. This would certainly help the apiculture farmers.

There are several works on the foraging behavior and characteristics of honeybees. In [1], honeybee foraging distances have been studied taking several samples and instances. In [1], 5484 different waggle dances (the characteristic dance of honeybees to communicate information among peers regarding the newly found forage) were decoded to analyze the foraging behavior and distances the honeybees travel to collect the forage. Their study included the collection of both nectar and pollens. The honeybees travel shorter distances for pollen collection while for the collection of nectar they go longer distances. In [2], the foraging behavior has been studied from the season and landscape points of views. It was found that the foraging behaviour depends very much on both these parameters. Even it was revealed from this work that the landscape details can be determined from the foraging habits of the honeybees [2]. In [3], a similar study has been conducted for the correlation between the landscape health and the foraging behaviors of the honeybees. A strong correlation was found to exist between these two parameters. Foraging is one of the distinct behaviors of honey bees (the common species is *Apis mellifera*) [4]. This behavior is the link between the honey bee colony and the ambient environment. Therefore, various in-colony and out-colony factors have significant impact on this behavior. Several studies have been employed to investigate these factors. In [4], the authors represented foraging activities including the regulation of foraging tasks, factors impacting this behavior, foraging preference, variations between subspecies, monitoring methods as well as the possible methods for controlling this behavior. In [5], a study was conducted in 2006 and 2007 designed to examine the foraging range of honeybees, in a 15.2 km^2 area dominated by a 128.9 ha alfalfa seed production field. They also studied several other alfalfa seed production fields (totaling 120.2 ha). In that study, each year honeybee self-marking devices were placed on 112 ha selected honeybee colonies originating from nine different apiary locations. The frequency of field collected bees possessing a distinct mark was similar, averaging 14.0% in 2006 and 12.6% in 2007. These data indicate that the marking devices placed at the entrances of selected hives effectively. In [6], the authors presented foraging behaviour using harmonic radars and reported the complete flight paths of displaced bees. In that study, the test bees forage at a feeder or are recruited by a waggle dance indicating the feeder. The flights are recorded after the bees are captured when leaving the hive or the feeder and are released at an unexpected release site. The authors in [7] present the waggle dances of honey-bees. These dances were decoded to determine where and how far the bees foraged during the blooming weather in August 1996 using a hive located in Sheffield, UK. The median distance foraged in that study was 6.1 km, and the mean was 5.5 km. It was found that only 10% of the bees foraged within 0.5 km of the hive whereas 50% went more than 6 km. 25% went more than 7.5 km and another 10% went more than 9.5 km from the hive. There are several models available on the statistical analysis and modeling of communication networks [8] - [14]. These models are used for the characterization and estimation of network parameters. In [9] and [10], statistical models and formulations have been presented for the dimensioning and fast calculation of optical network parameters. In [11], a statistical model for the link lengths of an optical network is developed from the convex area and the number of the nodes of the core networks. This model has been successfully applied for the estimation of link dependent parameters of the networks in [12]. A statistical model for the shortest path lengths of core networks is developed in [13]. This model can be used to find several path dependent parameters of networks. In [14], a novel method has been developed to estimate the statistical parameters of link statistical model. These estimations can be done using the major and minor axes of the circumferential ellipses of the networks.

In this work, we collect the honeybee foraging distances from several sources of six countries. We analyse this data and model them mathematically. From the analysis, we found that GEV distribution is fitting well to the foraging distances. We also estimated the parameters of the GEV distribution for this model.

The remaining parts of this article are organized in five different sections. In Section II, we present the basic features of honeybee foraging and their potential applications. In Section III, we present the characteristics of honeybee foraging networks. In Section IV, we present the data collection for this work and the sources of those data. In Section V, we present the model developed for the honeybee networks. In Section VI, we conclude this article with the main points of the model developed.

II. Honeybee Foraging Behaviour and Its Role in the Environment

The common honeybees forage around the hive in search of pollens and honey. Usually this resource constitutes food in the form of pollinating flowers. To analyze how these social organisms communicated exact distances and direction to one another in order to effectively locate these resources. Karl von Frisch determined that honeybees perform two distinct dance routines that coincide with two different distance approximations made by the foraging bee. These two dances, the round dance and the waggle dance, communicate to the other the approximate distance from the hive to the new resource. Only the waggle dance communicates direction.

The round dance is performed by the returning bee usually in complete darkness, vertically on a honeycomb. The circuitous motion attracts other foragers, which then learn that the resource is within approximately 50 meters of the hive. No direction is given by this routine. As a result, the newest foragers leave to search in all directions surrounding the hive. Behaviorally, this dance is energetically favorable due to the short distances travelled. In contrast, the waggle dance is energetically unfavorable to the individual, but beneficial to the hive.

The waggle dance is performed primarily when the resource is at a distance more than 50 meters. The returning forager either performs the dance on a vertical surface or a horizontal one. To determine distance and direction, the bee orientates itself relative to the sun. Any deviation from this point gives the angle the new foragers should pursue. If vertical, the bee orientates itself to gravity. Perpendicular to the ground becomes the reference point (i.e. the sun). Deviations from such relay direction accordingly. Distance is communicated by the length of the abdomen shake that forms the middle of a figure eight dance. Honeybees foraging behavior can be interpreted from a historical or adaptationist view [3]. Researchers in [6], performed historical analysis that reveals that distantly related bees might have evolved through 3 stages of development: First stage of the analysis shows that the genus *Trigona* conveyed direction by buzzing to gain their hivemates attention. The odors normally trap the bees to forage. The second stage normally involves marking the path from the resource to the hive with mandibular pheromones [6]. Then the queen bee buzzes and the collector bees follow the scent markers. In the third stage waggle dance is involved and it shows the direction of the pollens and honey. Foragers seek new resources to provide increased hive fitness. Through the waggle dance, the cost to benefit ratio is reduced [7].

Honeybees help the environment and the biosphere in several ways. Due to the increased human activities and the unlimited radiation pollution (due to mobile communication and vehicular radiations), honeybees are very much disturbed now. In order to restore their colonies and to make the environment balanced, there is a need to study the honeybee foraging networks. Apiculture is the study of beekeeping and it deals with several other aspects of hives and optimizing the harvesting. It also includes setting up properly located and constructed hives. This study can directly help the apiculture farmers to comprehend the foraging behaviors.

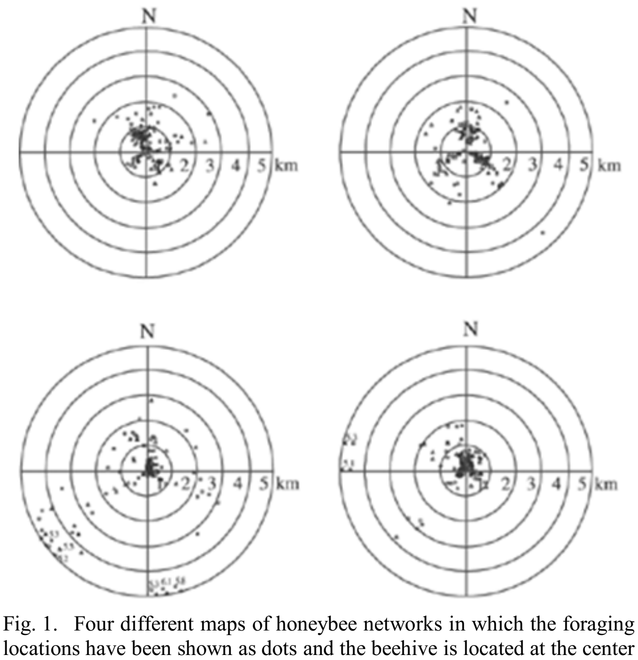

Fig. 1. Four different maps of honeybee networks in which the foraging locations have been shown as dots and the beehive is located at the center of the cicular map. We gather this data from [7] which was originally collected from the outskirts of Sheffield, UK.

Colonies of bees are highly socialized groups of insects that create their own ecosystems in and around their hives. A detailed understanding of how this society functions is necessary to get the most out of their system. Before even beginning to set up a beekeeping hobby or business, gaining a thorough knowledge of bee anatomy, behavior, and ecology is essential. It can provide essential basis for the bee keeping business. It has to be performed systematically and the models must be very much logical to explain the bee behaviors.

978-1-5090-4437-5/17/$31.00 ©2017 IEEE

Some of the hands-on processes of apiculture include constructing the hives and upkeep on these outdoor structures that can become weathered by the elements. Handling the bees can be one of the most difficult tasks. A smoker and proper clothing can help the bee keeper keep from getting stung while removing honeycombs or carrying out the delicate procedures of replacing the hive's bees. While it may seem strange to relate management techniques to bees, it is a vital skill. Beekeepers must know what the bees require before they can build a successful hive, including providing consistent sources of fresh water, nectar, and pollen. An individual who is both aware of it and respectful of the natural cycle of bees will find handling them much easier. However, he or she should also be alert to pests and threats to the hive before they become a real problem. Keeping an eye on rainfall charts, temperatures, climate changes, and information on area vegetation can help the alert beekeeper avoid or prepare for potential problems.

An important part of bee keeping is having knowledge of regional and national regulations regarding beekeeping. Honey is a food product, and as such, its preparation is subject to regulations. There are also rules about where hives can be placed in residential areas, and insurance concerns to be investigated as an ongoing part of the business.

III. Honeybee Foraging Network

The to and fro motions of the honeybees form several complex pathways. If the beehive is considered as a hub, then the locations of the forage and pollens can be considered as the nodes. These nodes can be taken as a tributary point or a feeder node. This is how we can consider the honeybee network as a communication network with a large central hub. These networks exhibit a star like topology. However, considering the intermediate hubs we can have a more diverse picture of the honeybee networks.

In Fig.1, we show four different cases of honey bee forging locations. In this figure, the beehive is located at the center of the circles. The forage and the pollens are located around the beehive. If each of the foraging points is connected with the hive (i.e., the center of the circle) if forms the complete honeybee foraging network. These networks can be considered as a small world network as every other point can be reached in just one or two hops. For this work of analysis of the link lengths, we considered the foraging locations as nodes and calculated the shortest distances between these locations and the center of the hives. In case of the multi hop paths, we measured the individual link lengths of each hop. All these link lengths are then analyzed for the appropriate statistical pattern.

IV. Foraging Data Collection

We collect the data for this work from different sources. Some of the data sources are from India and several are from other countries. In India, we contacted several researchers who work on honeybee foraging. We directly collected some data from the apiculture research group of Bangalore University. From these sources, we got both direct and indirect information for our model. The direct information is the readily available foraging distances. Indirect way is the non-availability of measured distances. Rather, we got the pictures and graphs drawn according to proper scales. We decoded the information from those sources.

We requested the honeybee researchers from the UK, Germany, Australia, USA, France and Egypt. From the majority of the researchers, we got positive responses and we got the foraging distances in different forms. We also used the data sources on foraging that are available as open sources. In addition to the above, we collected the data available from the previously published literatures. Altogether we collected 54 different sets of data for this work from 6 different countries including India. We analyzed all these 54 foraging networks for this study.

V. Statistical Modeling

We measured and analyzed all the link lengths available from the data collected from different sources. We used EasyFit to find the appropriate distribution for the honeybee foraging networks. The link lengths are continuous variables. Therefore, we used the continuous distributions to analyze the measured data. Altogether, we analyzed 65 different continuous distributions available in EasyFit. Out of these distributions, we found that general extreme value (GEV) distribution is the most suitable one for the modeling of honeybee networks. Each distribution fitting is tested using the appropriate statistic. In this case, we used Kolmogorov-Smirnov statistic (KSS) to check the quality of fitting. For the 54 honeybee networks used in this study, the average KSS value (averaged over the individual KSS of each honeybee network) was found to be 0.1648. This value is really small and thus very suitable for statistical modeling. The distribution having the smallest KSS among the 65 distributions used for analysis is GEV. In Fig. 2, we show the histogram of the link length distribution fitted with the GEV distribution. This analysis is similar to the communication network analysis presented in [8] – [14]. The KSS value for this particular fitting is: 0.1503.

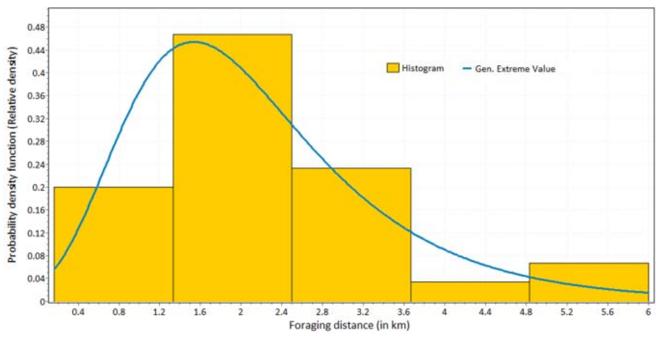

Fig. 2. Statstical distribution of the foraging distances from the bee hive for a real honeybee network. The blue line is the GEV distribution of the exact distances shown as histograms. The KSS for this fitting is: 0.1503.

As can be seen from Fig. 2, the majority of the foraging is done in the intermediate distances which are not very far from the beehives and also not very near as well. This is a typical pattern for all the honeybee networks. Therefore, the apiculture farmers can strategize the foraging areas according to the patterns normally observed. The beehive location optimization is required for maximizing the honey production. Certainly, this model can help in it.

VI. CONCLUSIONS

We developed a statistical model for the foraging distances of honeybees. This model is dependent on the average link length of the honeybee foraging network. The parameters of the developed GEV distribution depend on the average link length. Therefore, this model can be estimated from the convex area and the number of foraging location hubs. A statistical model for the honeybee foraging network is essential to understand their foraging behavior. It provides several key characteristics of the honeybees. As honeybees are essential for the environmental restoration and pollination of grains, their foraging behavior has a lot of importance. Using the model developed in this work, the distance related aspects of foraging can be understood quite well. The apicultural aspects can also be taken into consideration from this model. The forage and pollen locations can be optimized for practical cultivation purposes. This is how the farmers can leverage from better pollination of grains and higher yield of honey from apiculture.

REFERENCES

[1] M. J. Couvillon, F. C. R. Pearce, C. Accleton, K. A. Fensome, S. K. Quah, E. L. Taylor, and F.L. Ratnieks, "Honey bee foraging distance depends on month and forage type," Apidologie, vol. 46, no. 1, pp. 61-70, Jan. 2015.

[2] N. Danner, A. M. Molitor, S. Schiele, S. Härtel, and I. Steffan-Dewenter, "Season and landscape composition affect pollen foraging distances and habitat use of honey bees," Ecological Applications, vol. 26, no. 6, pp.1920-1929, Jun. 2016..

[3] M. J. Couvillon, and F. L. W. Ratnieks, "Environmental consultancy: dancing bee bioindicators to evaluate landscape 'health'," Ballroom Biology: Recent Insights into Honey Bee Waggle Dance Communications, p.59, Mar. 2016.

[4] H. F. Abou-Shaara, "The foraging behavior of honey bees, Apis mellifera: a review," Veterinaries Medicines, vol. 59, no.1, pp. 1 – 10, 2014.

[5] J. R. Haglerand, A. V. Deynze, S. Mueller, L. R. Teuber, and S. A. Machtley, "Foraging range of honey bees, Apis mellifera, in alfalfa seed production fields," Journal of Insect Science, vol. 11, no.1, pp. 1 – 12, 2011.

[6] R. Menzel, et. al., "Honey bees navigate according to a map-like spatial memory" Proceedings of National Academy of Science, vol. 102, no. 8, pp. 3040 – 3045, 2005

[7] M. Beekman, and F. L. W. Ratnieks, "Long-range foraging by the honey-bee, Apis mellifera L." FunctionalEcology,vol. 14, no. 4, pp. 490 – 496, 2000.

[8] S. K. Routray, C. Pavan, G. Sahin, J. R. F. da Rocha, and A. N. Pinto, "Statistical Analysis and Modeling of Optical Transport Networks: Characterization and Application," in Proc. of Telecommunication Conference, Aveiro, Portugal, Sep. 17 – 18, 2015.

[9] S. K. Korotky, "Network global expectation model: A statistical formalism for quickly quantifying network needs and costs," IEEE/OSA J. of Lightwave Technol., vol. 22, no. 3, pp. 703–722, Mar. 2004.

[10] J. F. Labourdette, E. Bouillet, R. Ramamurthy, and A. A. Akyama, "Fast approximate dimensioning and performance analysis of mesh optical networks," IEEE/ACM Trans. Netw., vol. 3, no. 4, pp. 906 – 917, Aug. 2005.

[11] S. K. Routray, R. M. Morais, J. R. F. da Rocha, and A. N. Pinto, "Statistical model for link lengths in optical transport networks," IEEE/OSA J. Opt. Commun. Netw., vol. 5, no. 7, pp. 762 – 773, Jul. 2013.

[12] S. K. Routray, G. Sahin, J. R. F. da Rocha, and A. N. Pinto, "Estimation of Link-Dependent Parameters of Optical Transport Networks from the Statistical Models," IEEE/OSA J. Opt. Commun. Netw., vol. 6, no. 7, pp. 601 – 609, July 2014.

[13] S. K. Routray, G. Sahin, J. R. F. da Rocha, and A. N. Pinto, "Statistical Analysis and Modeling of Shortest Path Lengths in Optical Transport Networks," IEEE/OSA J. of Lightwave Technol., vol. 33, no. 13, pp. 2791 – 2801, Jul. 2015.

[14] S. K. Routray, J. R. F. da Rocha, and A. N. Pinto, "Estimating the Parameters of Optical Transport Networks from their Circumferential Ellipses," in Proc. of IEEE Int. Conf. on Telecommunications (ICT), Lisbon, Portugal, May 4 – 7, 2014.

978-1-5090-4437-5/17/$31.00 ©2017 IEEE