Search Theory based Routing in AUDTHMN

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Summary
Search Theory is a major discipline within the field of operations research, whose application range from deep-ocean search for submerged objects to deep-space surveillance for artificial satellites. DTN deals with networks in challenged environment. DTN focuses on deep space to a broader class of heterogeneous networks that may suffer delay and disruptions. Such networks may be affected by design decisions such as naming and addressing, message formats, data encoding methods, routing, congestion management and security. AUDTHMN is an application to monitor Blackbuck habitat and also a DTN test bed. Search Theory based DTN routing in AUDTHMN is simulated using Alunivdtnsim. Hide effort among the various demographic groups of blackbuck has been considered as the parameter to forward the DTN bundle from individual radio collared bucks to the data collector and hence the data center. The Simulation results are graphically shown using Gnu plot.

Key words:
DTN - Delay and Disruption Tolerant Networking, IPN – Inter Planetary Internet, AUDTHMN- Alagappa University Delay Tolerant Habitat Monitoring Network, Alunivdtnsim – Alagappa University Delay Tolerant Network Simulator, LTP – Lick Lider Transmission Protocol, Lebesgue Measure, Nyquist rate.

1. Introduction

Delay and Disruption Tolerant Networking (DTN) [7] [10] refers to broad class of Wireless Ad-hoc networks that operate in challenged environments plagued by delays and disruptions [12]. DTN is part of the Inter Planetary Internet, an initiative started at the Jet Propulsion Laboratory (JPL) by Vint Cerf et.al. DTN has evolved over the years with major research contributions from academicians and Industry. DTN is a network of regional networks. It acts as a overlay on regional networks. DTN supports interoperability by accommodating mobility and low Radio Frequency (RF) power capabilities of the nodes involved. DTN includes RF, Ultra Wide Band (UWB) networks, Optical and Acoustic networks. Though simultaneous connectivity may be absent, a combination of store & forward, along with node mobility makes message delivery possible. The bundle protocol [8] is a DTN protocol based on overlay technique. It can be used on any convergence layer such as TCP, UDP and LTP. The Lick-Lider Transmission protocol [11] is another DTN specific protocol operating at convergence layer. While the bundle protocol moves data packets (bundles) end to end, the LTP is more of a point to point type. While the space applications, which are the primary beneficiaries of the DTN [10] have provided ample scope for its research, many terrestrial applications have been conceived that use and contribute to DTN research. Few of such terrestrial applications [11] include:

(i) Reindeer herd tracking by the Saami tribesmen in Arctic Circle.
(ii) Zebra tracking [23] to monitor the movement of zebra and manage their habitat effectively in Africa.
(iii) Early detection of the invasion of Australian cane toads, a pest and invasive species in non-native regions.
(iv) Seismic monitoring in Mexico for early warning system against earth quakes, volcano and land slides.
(v) SenDT – an initiative by the Trinity College Dublin Ireland to monitor lakes in Ireland.
(vi) DTN - Simple Text Message application over android OS introduced in Nexus One Cellular phones by Google Inc.
(vii) AUDTWMN[29] – A proposed water monitoring application and Test bed for DTN research [2][3][4].

Based on DTN's applicability for a multitude of terrestrial applications [9], the authors devised upon a DTN based Habitat monitoring network [24] that will serve the dual purposes of Wildlife conservation and research. It can be used to monitor habitat parameters of Blackbuck [17] (Antelope Cervicapra) in wildlife context and as a test bed for DTN in research context. Monitoring habitat of Blackbuck in Vallanadu Sanctuary in district of Tuticorin [19] seemed to be an important wildlife conservation need due to the following reasons:

(i) Blackbuck population has been hugely decimated in India due to indiscriminate hunting prior to Independence, followed by developmental pressure, mining and agricultural needs in recent times.
(ii) The Vallanadu sanctuary is small with area of 16.41 square kilometers with small Blackbuck population restricted to the hillock comprising the sanctuary.

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(iii) The forest type is thron scrub composed of thorny hardwood and xerophytes. The vegetation is mainly scrub forest with thick acacia growth that prevents assessment of the Blackbuck numbers.
(iv) The sanctuary receives scant rainfall and is characterized by hot, dry summers and cold, wet winters.
(v) The Blackbucks have regular habit of coming out of the scrubs and graze on the fallow lands adjoining the sanctuary.

With all the above factors, combined with absence of sophisticated surveillance methods, constant monitoring of habitat parameters and knowledge of their territorial behavior helps to better manage them for conservation and preservation. The rest of the paper describes the design considerations for the proposed AUDTHMN and its routing [15] based on Search Theory [16].

2. Design Considerations

AUDTHMN application intends to monitor the movement of the Blackbucks [19] in the Vallanadu Sanctuary. The application is also scalable so as to accommodate other habitat parameters such the water holes, salt pits and noise levels in the sanctuary. The application must lend itself to be a research tool by enabling simple interface and reconfigurable components. With all these pre-requisites the following design has been conceived by the authors.

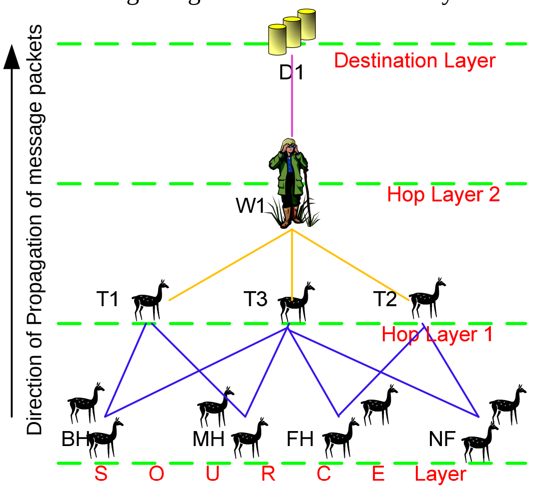

Fig. 1 Schematic of the proposed AUDTHMN.

Vallanadu Sanctuary is abode to about 30 Blackbucks which are considered as endangered. Going with normal demographic distribution [17], It is assumed that 3 are Territorial males (T123), 2 Nursing females (NF), 5 Bachelor bucks in a herd (BH), 5 Female does in another (FH), 2 Males and 3 Females in another herd (MH) and the rest may be fawns and sub-adults that are part of one of the above herds. The proposed application involves fitting a percentage of the Blackbuck population with radio collared DTN nodes. The DTN nodes comprise of GPS data logger that keeps recording the location of the Blackbuck at regular intervals of time. The collected data is then transferred to the Data collector who may be a wild life staff in-charge of collecting the statistics of the Blackbucks. No permanent or semi permanent infrastructure exists as intermediate hop-layer between the Blackbuck nodes and data collector. The Data collector goes in search of the Blackbucks on scheduled frequency such as daily basis. His goal would be to use minimal search effort in finding the bucks and hence the data.The routing of data from Blackbucks to the Data collector is hence influenced by the search methods [18] of the Data collector and the hiding behavior of the Blackbucks. The authors propose to use dtn2.5 on the nodes. The dtn2.5 running on Ubuntu Linux 9.10 platform serves as excellent DTN nodes [6]. In lab environment, DTN bundles were successfully sent across using the bundle protocol.

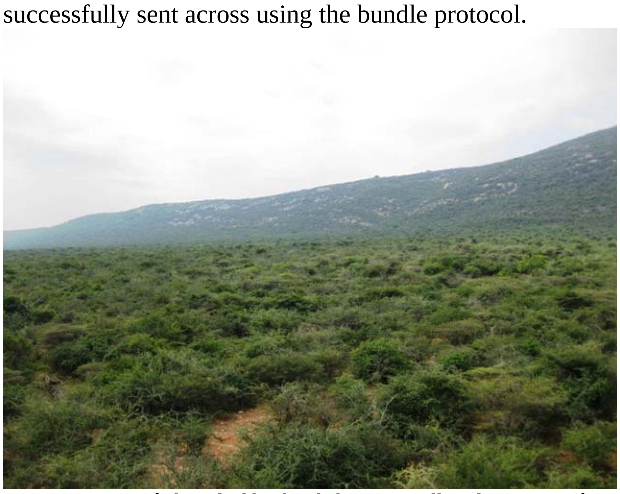

Fig. 2 A view of the Blackbuck's habitat in Vallanadu as seen from outside the Sanctuary using 12X zoom. It shows the thick vegetation that makes the assessment and monitoring difficult.

3. Simulation Considerations

The Alunivdtnsim [5] is a DTN simulator written in C Language [28]. It has been designed to be simple and user friendly to meet the needs of amateur researchers. The Alunivdtnsim is configured with the following simulation [20][21][22] set up so as to closely mimic the AUDTHMN. The Alunivstnsim simulates the function and synthetic movement of its constituent agents namely 1. Blackbucks (Various social groups) 2. Data Collector (Wild-life staff) and 3. Data centre.

3.1 Territorial Bucks

These are adult male Blackbucks that are territorial in nature. They restrict their movement to their territory which in this case is 1 square Km. The territorial bucks are bold and do not flee even if approached by the data collector w1 up to 50 feet. They wait for doe to walk into their territory so that they can try their chance of propagating their genes through courtship leading to progeny.

Fig. 3 A Territorial blackbuck is on watch of his territory at Maidenahalli Blackbuck Reserve, Karnataka. The termite hill on the right is a natural landmark for territorial demarcation.

When other bucks walk in, they defend their territory using various tactics including confrontation as the last resort. The Vallanadu sanctuary is assumed to have 3 territorial bucks "T1,T2 and T3" in simulation of AUDTHMN. The demarcation by the buck itself is by a patterned defecation and de-urination along the boundary of its territory.

Fig. 4 Territorial demarcation created by Territorial Blackbuck by means of patterned defecation at Maidenahalli Blackbuck Reserve, Karnataka.

3.2 Bachelor Herd

These are adult and sub-adult male Blackbucks that are non-territorial in nature and graze about as a herd. While all the male bucks may be radio tagged, only one radio is kept active as the other radio collars would also give similar data. The DTN message packets have the buck ID which enables identification of the source. When a bunch of packets show similar GPS reading and are identified to be adult and sub-adult males, they are tagged as a bachelor herd and reading from only one collar among the herd is considered. Such a representative DTN agent is the bachelor herd "BH". The term Bachelor herd implies that based on their current social status, they have less chances of courtship with doe(s) in comparison with the territorial bucks.

Fig. 5 A Bachelor herd at Maidenahalli Blackbuck Reserve, Karnataka.

3.3 Mixed Herd

These are herds with animals from both genders. The Bucks and the Does co-exist as a herd. As in the case of bachelor herd, the grouping as one DTN agent "MH" is done when a bunch of packets show similar GPS reading and are identified to be males and females. Because of the demographic mixture, the Mixed herd is one of the most harmonious and is capable of mingling with bucks belonging to the other social category. Hence they play an important role as efficient data mules.

Fig. 6 A Mixed herd at Maidenahalli Blackbuck Reserve, Karnataka.

3.4 Female Herd

These are adult and sub-adult female Blackbucks that are non-territorial in nature and graze about as a herd. While all the female Does may be radio tagged, one radio is kept active as the other radio collars would also give similar data. The DTN message packets carry Buck ID which enables identification of the source. When a bunch of packets show similar GPS reading and are identified to be adult and sub-adult females, they are tagged as a female herd and reading from only one collar among the herd is considered. Such a representative DTN agent is the female herd “FH”.

Fig. 7 A Female herd at Maidenahalli Blackbuck Reserve, Karnataka.

3.5 Nursing Female

These are Does that have given birth to offspring recently and currently nursing the fawn. As the fawn is too young to protect, the mother Doe avoids exposing the fawn. They are elusive and retire to protected place during most of the day. Such a female when radio collared is the DTN agent named Nursing Female “NF”. While they may cautiously come in contact with Female herds & Mixed herds, they try to avoid the other social groups.

Fig. 8 Female Doe(s) with fawns at Maidenahalli Blackbuck Reserve, Karnataka. Note 3 fawns at the right side of the photo.

3.6 Data Collector

A Wild-Life staff who is assigned the task of maintaining the census and statistics of the Blackbucks shall be the Data Collector. He carries a DTN device that is capable of assimilating the DTN message packets from the Blackbucks. This portable device carried by the Data Collector is the DTN agent “W1”. Being a wild life sanctuary, no permanent infrastructure is commissioned to collect the message packets. It is the Data Collector who walks portions of sanctuary searching for the bucks to make radio contact and hence collect the message packet. It is desirable for the Data Collector to make least search effort so as to locate the buck that gives the most data (not only it’s own, but also from other elusive bucks).

3.7 Data Centre

The Data Centre is the permanent infrastructure on the fringe on the Sanctuary where the data collected by the DTN device carried by the wild-Life staff is taken for analysis and archival. The Data centre has better infrastructure in terms of a permanent power source and building structure safe from elements. The DTN agent namely the Data Centre D1 has more memory (3500 words) to accommodate reading from all the bucks that have been radio collared.

Fig. 9 Watch towers such this as seen from outside the Vallanadu sanctuary may be used as data centers with appropriate weather proof enclosure.

3.8 Message packet

The Message packet is simple comprising only 3 types of info embedded in it as shown in figure 10. They are:

16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Fig. 10 AUDTHMN Message Packet layout in Alunivdtnsim

1. Buck ID, an unique identification code announcing the source of that message packet. Bits 12-16 contain the Buck ID.
2. X axis co-ordinate, which contains East-West grid location in which the message packet was generated. The GPS readings from the GPS logger in the radio collar are resolved to compute the East-west grid location. Bits 7-11 contain the X axis co-ordinate.

3. Y axis co-ordinate, which contains North-South grid location in which the message packet was generated. The GPS readings from the GPS logger in the radio collar are resolved to compute the North-South grid location. Bits 1-6 contain the Y axis co-ordinate.

4. Simulation Schematic

The Vallanadu Sanctuary is geographically divided into 25x32=800 grid cells. The East-West length of the sanctuary and its immediate surrounding running 6.25 km is divided into 25 columns. The North-south length of the sanctuary and its immediate surrounding running 8 Km is divided into 32 rows. Together, the whole sanctuary is divided into 800 grid cells which are square in shape and measuring 250 meters to a side. The formation of grid helps in quantization of the buck location based on GPS co-ordinates so that enormous amounts of location data are not generated. A buck located any where within the 250mx250m will generate the same location identifier otherwise known as the grid cell coordinates. The extreme South-west cell has x coordinate 0 that increases moving east (Max 24). It also has y coordinate 0 that increases moving north (Max 31).

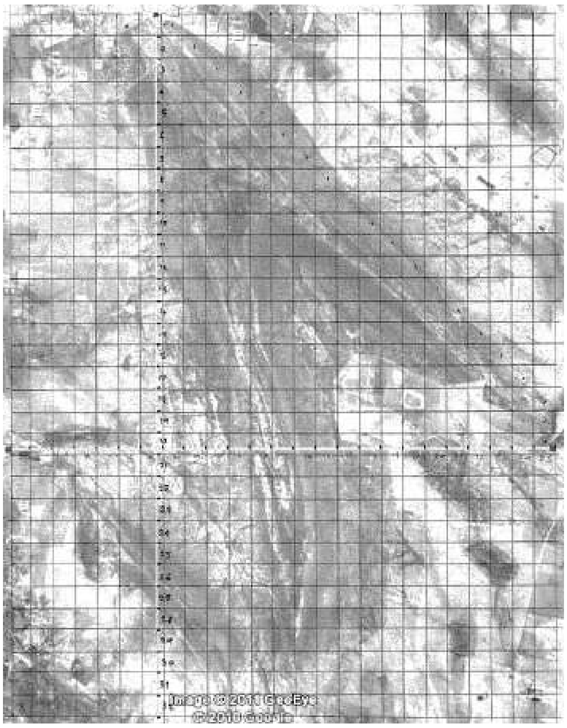

Fig. 11 Grid overlay on the Satellite imagery showing Vallanadu Blackbuck sanctuary.

4.1 Global tick

At the heart of the simulator is the global-tick counter that produces the simulation tick. One global-tick is simulated to mimic 5 seconds of real time based on the fastest participating agent namely the Blackbuck. Movement modeling [25] of Blackbuck takes into consideration the upper limit of its pace which is 80 Km per hour or 22.22 meters per second. In order for a Blackbuck's position to be captured faithfully, the Nyquist rate [26] for sampling must be met. This demands that at least 2 samples have to be taken within 250 meters so that no habitat cell reading goes unlogged from a buck in sprint. A Blackbuck with top speed can cross the 250 meters of the a grid in 11.25 seconds. To meet the Nyquist rate, 2 samples have to be taken within that time and hence a sample must be made every atleast 5.6 seconds. Hence a convenient 5 seconds is chosen as one global-tick for the simulation. As a buck will not be in full pace all the time, a pace modulator function randomly decides of the pace of buck anywhere between 80 km/hr to 0 at any given tick.

4.2 Functions

For every global-tick a series of functions each simulating the participating agents is called. These functions are named T1,T2,T3,BH,MH,FH,NF,W1 and D1. They simulate the Territorial bucks 1,2,3, the Bachelor herd, the Mixed herd, Female herd, Nursing female, Data collector and the Data centre respectively. Whether any of these functions has to be invoked for a particular global-tick is decided by a pacemodulator function. The pacemodulator function uses a rand library function to randomly make the decision. All the functions except D1 model synthetic movement. T1,T2 and T3 are restricted to move only among their respective 16 grid cells to mimic their territorial nature. BH,MH,FH and NF are free to roam about in any of the grid cells. All agents except W1 and D1 keep logging their own grid coordinates as they move. Their movements are modeled based on random walk [27]. T1,T2,T3,BH,MH,FH and NF in turn call 2 common functions namely searchtheoryrouting and mapgridtolinearmemory.

4.3 Search Theory Routing

Searchtheoryrouting function as the name implies is the heart of the simulator that implements the search theory [16][18] based routing functionality. Hide effort is the important deciding routing parameter.

Hide effort = (1-epsilon)*(u/g) (1)

where u is the Lebesgue measure of the search area normalized to 1 as the search are remains the same, g is the discovery rate that gets incremented every time that particular agent comes in contact with data collector "W1".Epsilon is any value greater than 0 and it is chosen to be 0.1 in this case. This function makes an assessment if a particular node calling this function is in contact with another node. Then the hide efforts of the nodes in contact are sorted in ascending order. Then the node that has the least hide effort is chosen as the node to which the message packet has to be forwarded. If more than one node in contact has the same hide effort, it will forward to both (provided multi-copy routing is enabled). The node also saves the hide effort of the DTN node to which it has forwarded the packet based on its search theory routing decision. This will be used by the DTN agent the next time it attempts to forward the message packet as follows. When the node knows that it has indeed contacted a DTN node of lower hide effort (in the past) than the one it currently has come in contact with, it does not forward the message packet. It waits to come in contact with a DTN node whose hide effort is equal to or lower than the DTN node to which it has forwarded earlier. This helps in avoiding inferior routing decisions by remembering historical routing decisions and providing hope that it may come in contact with other DTN node(s) with better hide effort. Time to Live (TTL) is not implemented in AUDTHMN as the data is not time sensitive. What is important is whether the animals' strayed into certain grid cells outside the sanctuary that are potentially dangerous to their survival. Hence as part of routing, duplicate packets [14] are deleted as and when they are found.

4.4 Map Grid to Linear Memory

Mapgridtolinearmemory function, as the name implies converts the GPS log in the form of a 2 dimensional grid coordinate into message packet of size word (2 bytes). They are the stored in a linear memory that can hold up to 2000 words. The 2000 word limit in simulation makes the DTN problem interesting. While each DTN node will generate 800 message packets (and hence words) at max if they roam around the entire sanctuary and its adjoining areas being monitored, the rest of the 1200 words memory location can be used to relay message packets by acting as data mules. Note that the territorial bucks generate only 16 message packets max, and the rest are for storing-forwarding (an important aspect in DTN world!) message packets generated by other nodes. Thus the territorial bucks act like throw boxes [1], only with the difference that they themselves do generate message packets too.

4.5 Other Functions

The W1 function models the movement in a particular pattern. Based on the sightings, the Data collector identifies a few territorial bucks (3 in our case), that will require the least search effort to find. He then walks along the path that connects the territorial Buck locations enroute starting from and ending at the data centre in a loop. The search effort per trip is an important consideration which is desirable to be kept minimal. Search Theory based DTN routing aims at exactly accomplishing the same (i.e., reducing the search effort of the data collector). Once W1 reaches the data centre D1, the packets are transferred to the repository in D1 and the radio is disabled. This prevents stale contacts from being made continuously when W1 is stationary within D1's radio vicinity.

D1 keeps pulling fresh data from W1 when it comes in radio contact. D1 is stationary and hence does not need movement modeling. W1 simulates the movement of the data collector walking at about 8 Km per hour, each round trip.

The disruption function models disruption events happening during radio contact and when message packet transfer is in progress. It uses a rand library function that randomly decides whether a particular message packet transfer should be disrupted or not. In the sanctuary, there are 2 disruption possibilities that have been considered.

1. Any occlusion in the line-of-sight radio propagation (802.11 operates at 2.4 GHz) due to physical aspects such as topographical relief (note that Vallanadu Sanctuary is on a hillock) or thick vegetation coming in between.
2. Agents that were in radio contact may go out of range due to their physical movement. With the Bucks capable of dashing at 80 Km per hour, this scenario is equally probable.

5. Simulation Run

The Alunivdtnsim simulating AUDTHMN can be run typically for 30 days (518400 Global ticks). But in our case it is run only for 7 days (120960 Global ticks). The results of the simulations are captured in the following data log files:

1. radiocontactlog.dat (Records each radio transfer)
2. w1gpslog.dat (W1's GPS log)
3. t1gpslog.dat (T1's GPS log)
4. t1dtnlog.dat (T1's GPS log reaching data centre)
5. t2gpslog.dat (T2's GPS log)
6. t2dtnlog.dat (T2's GPS log reaching data centre)
7. t3gpslog.dat (T3's GPS log)
8. t3dtnlog.dat (T3's GPS log reaching data centre)
9. bhgpslog.dat (BH's GPS log)
10. bhdtnlog.dat (BH's GPS log reaching data centre)
11. mhgpslog.dat (MH's GPS log)
12. mhdtnlog.dat (MH's GPS log reaching data centre)
13. fhgpslog.dat (FH's GPS log)
14. fhdtnlog.dat (FH's GPS log reaching data centre)
15. nfgpslog.dat (NF's GPS log)
16. nfdtnlog.dat (NF's GPS log reaching data centre)

The results of the simulations are graphically analyzed using a tool called Gnu plot [5]. Gnu plot is widely used open source program for plotting and visualizing data.

Graphical analysis involves the following basic steps:
1. Plot the data
2. Inspect it, trying to find some recognizable behavior.
3. Compare the actual data to data that represents the hypothesis from previous step.
4. Repeat.

The data log generated by Alunivdtnsim can be used to carry out Data analysis and visualization. Some of these analyses include but not limited to
1. Graphical analysis
2. Presentation graphics
3. Control charts
4. Reality representation
5. Image analysis
6. Statistical analysis
7. Exploratory data analysis

The simulator is run with single copy Search Theory routing and the data is logged to analyze the performance.

6. Simulation Results

The simulation results which are captured in the *.dat files are graphically presented in figures in this section. Fig 12 is a 3 dimensional graph where-in a “+” plots radio contact between nodes (denoted along Y and Z axis) as and when they happen at a given global tick (X axis).

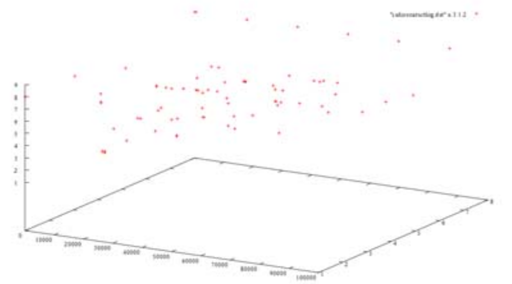

Fig. 12 Radio contacts between nodes show in 3D. X axis is global ticks, Y and Z axes represent the DTN node ID.

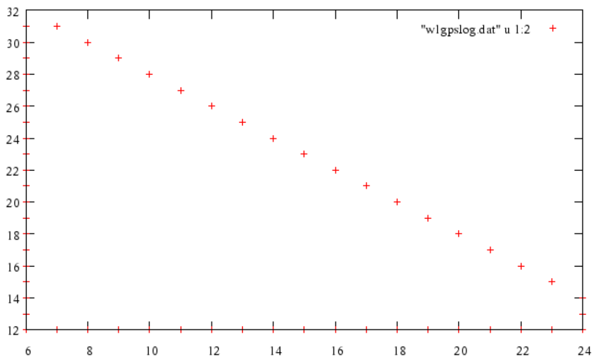

Fig. 13 Actual GPS log of the DTN agent W1.

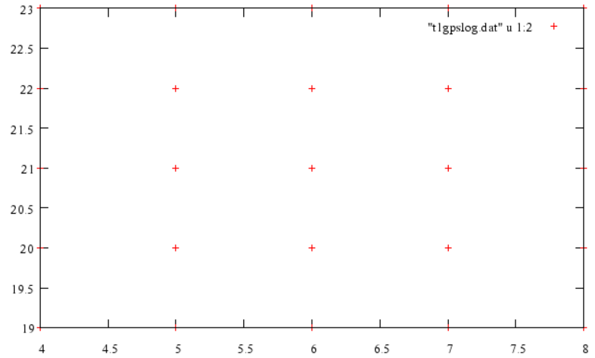

Fig. 14 Actual GPS log of DTN agent T1

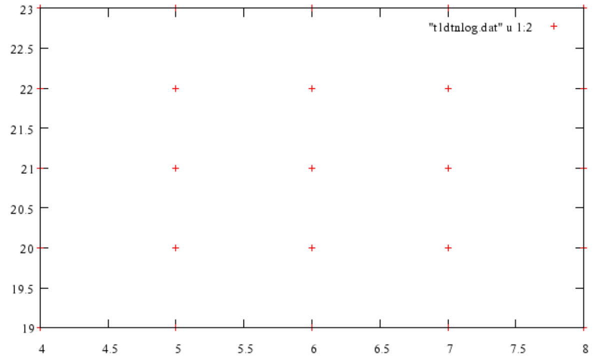

Fig. 15 GPS log of T1 as received at D1.

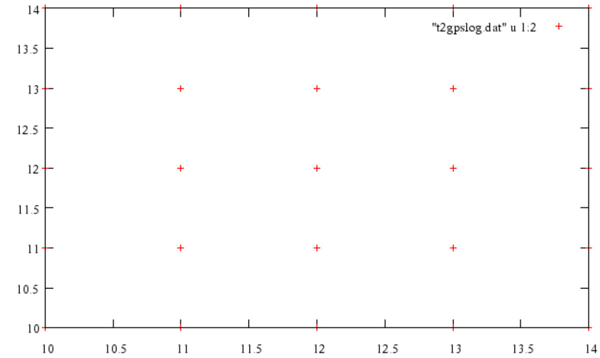

Fig. 16 Actual GPS log of DTN agent T2

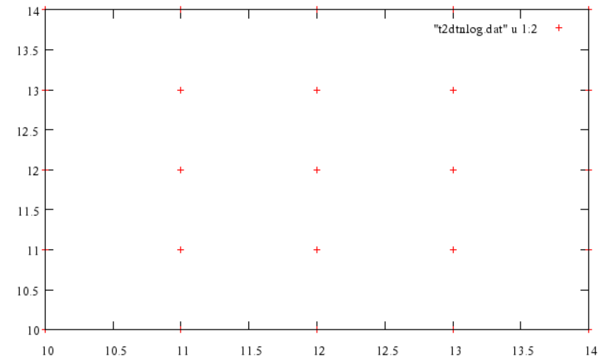

Fig. 17 GPS log of T2 as received at D1

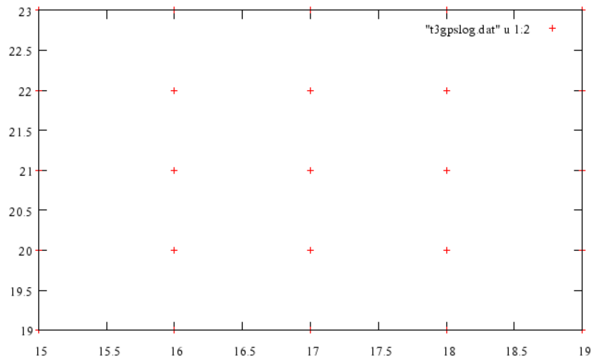

Fig. 18 Actual GPS log of DTN agent T3

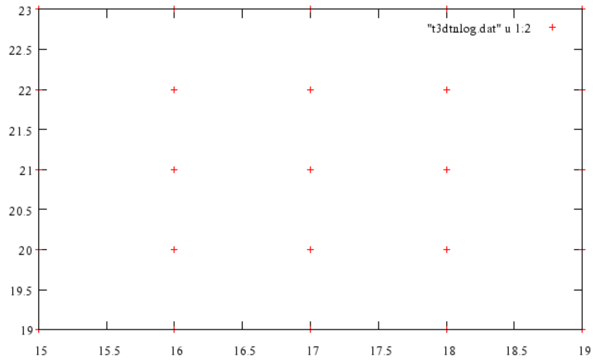

Fig. 19 GPS log of T3 as received at D1

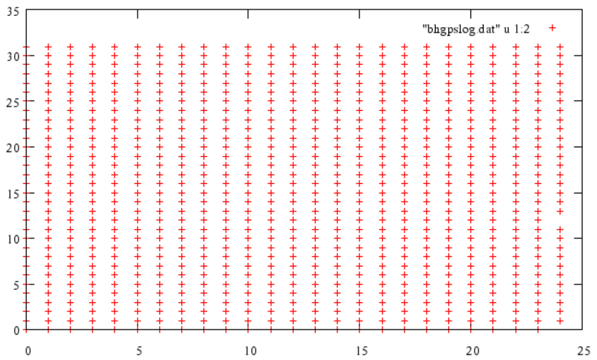

Fig. 20 Actual GPS log of DTN agent BH

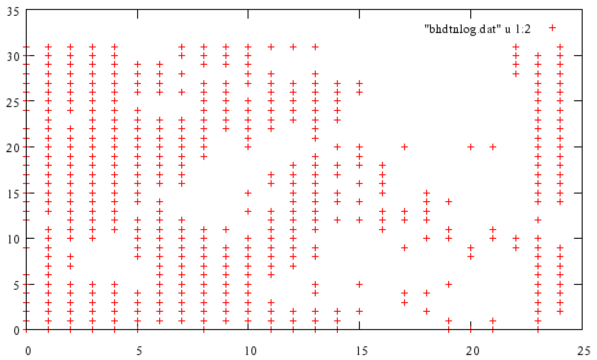

Fig. 21 GPS log of BH as received at D1

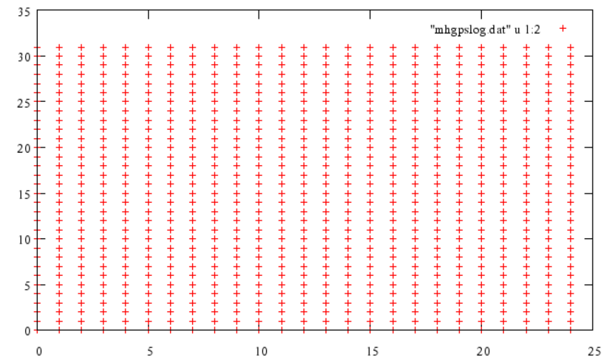

Fig. 22 Actual GPS log of DTN agent MH

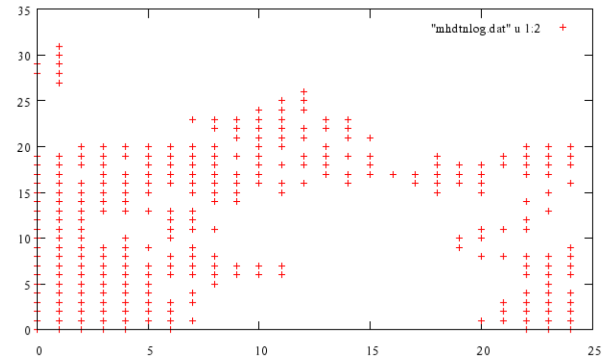

Fig. 23 GPS log of MH as received at D1

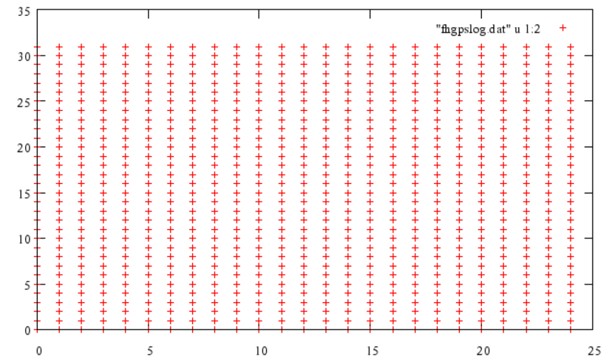

Fig. 24 Actual GPS log of DTN agent FH

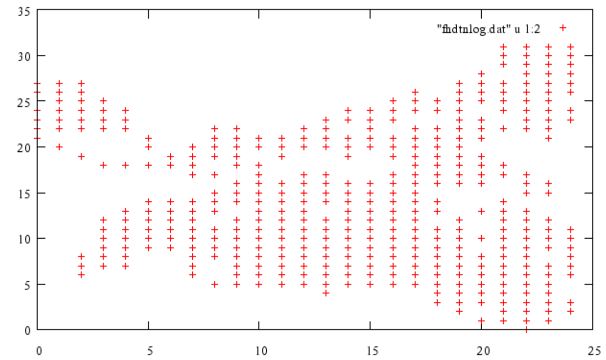

Fig. 25 GPS log of FH as received at D1

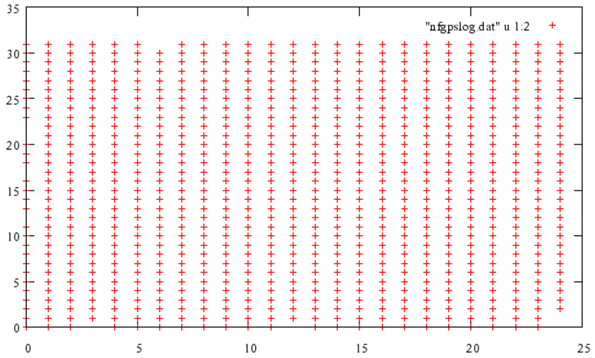

Fig. 26 Actual GPS log of DTN agent NF

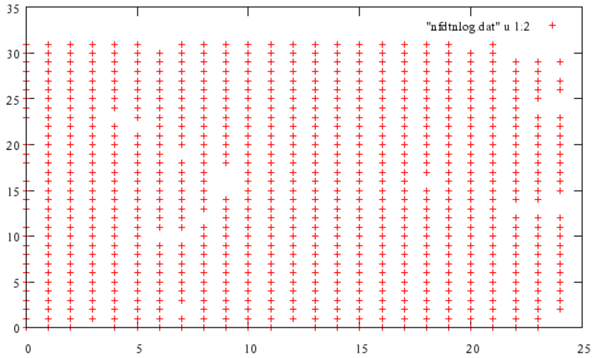

Fig. 27 GPS log of NF as received at D1

Fig 13 shows the path taken by data collector that connects 3 (pre-located) territorial Blackbucks en-route. Fig 14, 16, 20, 22, 24 and 26 are 2 dimensional graphs plotting the actual recorded presence of the respective agent in specific grid locations (out of 800). It is marked with "+" at the intersection of the East-West co-ordinate (X axis) and North-South coordinate (Y axis). Fig 15, 17, 19, 21, 23, 25 and 27 depicts the GPS logged co-ordinate grid info that had been transmitted thru Search Theory routing along AUDTHMN and what has finally been received at the data centre. Throughput is defined as the percentage of message packets received at data centre to actual message packets generated by the agents as they move. The throughput statistics for 7 days of simulation is as follows:

1. t1's throughput is 100.000000 %
2. t2's throughput is 100.000000 %
3. t3's throughput is 100.000000 %
4. bh's throughput is 59.022556 %
5. mh's throughput is 36.500000 %
6. fh's throughput is 49.500000 %
7. nf's throughput is 96.713021 %

It has been observed that for a given optimal search effort, the throughput tends to increase with the number of days of simulated habitat monitoring.

6. Conclusion

This paper simulates the use of Search Theory as routing policy [13] for DTN bundle routing. Being a simulation, the paper does not discuss experimental treatment or results which may be beyond its scope. A glimpse of the proposed Alagappa University Delay Tolerant Habitat Monitoring Network, a wild life conservation application, has also been presented. This research is at the early conceptual stage for AUDTHMN. The future scope of work proposed by the authors includes:

(i) Experimentation and subsequent implementation of Search Theory routing in DTN bundles.
(ii) The results of Search Theory Routing schemes applied in AUDTHMN to be theoretically extrapolated to the Inter-planetary counterparts.
(iii) Field testing of AUDTHMN and its delivery performance
(iv) Physical realization of AUDTHMN, deployment and operation at Vallanadu Blackbuck Sanctuary.
(v) Search Theory routing for other applications such as Smart sensors in Battle field, ZebraNet, Swarming Micro Air Vehicle Network, etc.,

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References

[1] Laveen Sundararaj, Palanisamy Vellaiyan, "Throughput Enhancement in AUDTWMN using Throwboxes – An Overview", ICIWE 2010 : International Conference on Internet and Web Engineering, Singapore August 25-27, 2010. ISSN: 2070-3740 & ISSN: 2070-3724.
[2] Laveen Sundararaj, Palanisamy Vellaiyan, "Delay Tolerant Networking routing as a Game Theory problem – An Overview", International Journal of Computer Networks, Kuala Lumpur, Volume (2): Issue (3). ISSN 1985-4129.

[3] Laveen Sundararaj, Palanisamy Vellaiyan, “Delay Tolerant Network Routing based on Rendezvous value (R) – A Theoretical Overview”, European Journal of Scientific Research, London, Vol 43 Issue 2 June 2010, ISSN: 1450-216X / 1450-202X.
[4] Laveen Sundararaj, Palanisamy Vellaiyan. “DTN Routing based on Search Theory – An Overview”. International Journal of Computer Science and Network Security, Korea, Volume 10, Number 11, November 2010. ISSN: 1738-7906.
[5] Laveen Sundararaj, Palanisamy Vellaiyan. “Alunivdtnsim – An Overview of a simple Delay Tolerant Network simulator”. In Proceedings of the National Conference on Information, Communication & Networking, SRM EEC Chennai, April 2010.
[6] Laveen Sundararaj, Palanisamy Vellaiyan, “DTN Work Update”, DTNRG meeting March 2009, a NASA event, Google HQ, CA.(http://down.dsg.cs.tcd.ie/dtnrg-at-google/)
[7] Kevin Fall, Senior Member, IEEE, and Stephen Farrell, "DTN: An Architectural Retrospective", IEEE Journal on Selected Areas in Communications, Vol.26, No 5, June 2008.
[8] K. Scott and S. Burleigh, “Bundle Protocol Specification,” Internet RFC 5050, Nov 2007.
[9] Laveen Sundararaj, Palanisamy Vellaiyan, “Planned DTN Work”, DTNRG meeting May 2007, Trinity College Dublin, Ireland. (http://down.dsg.cs.tcd.ie/misc/DubDTN/)
[10] V. Cerf, S. Burleigh, A. Hooke, L. Torgerson, R. Durst, K. Scott, K. Fall, and H. Weiss, “Delay–Tolerant Networking Architecture,” Internet RFC 4838, April 2007.
[11] S. Farrell and V. Cahill, Delay– and Disruption–Tolerant Networking. Artech House Publishers, 2006, ISBN: 1-59693-063-2.
[12] Stephen Farrell, Vinny Cahill, Dermot Geraghty, Ivor Humphreys and Paul McDonald, “When TCP Breaks, Delay- and Disruption-Tolerant Networking", IEEE Internet Computing July-August 2006.
[13] Zhensheng Zhang, “Routing in intermittently connected mobile ad hoc networks and delay tolerant networks: overview and challenges” Communications Surveys & Tutorials, IEEE, Volume 8, Issue 1, First Quarter 2006 Page(s):24 – 37.
[14] Thrasyvoulos Spyropoulos, Konstantinos Psounis, and Cauligi S. Raghavendra, “Single-copy routing in intermittently connected mobile networks”, Proc. Sensor and Ad Hoc Communications and Networks SECON, pages 235-244, October 2004.
[15] Sushant Jain, Kevin Fall, and Rabin Patra, “Routing in a delay tolerant network”, SIGCOMM '04: Proceedings of the 2004 conference on Applications, technologies, architectures, and protocols for computer communications, pages 145-158, New York, NY, USA, 2004. ACM.
[16] D. Chudnovsky and G. Chudnovsky, Search Theory. Marcel Dekker, Inc, 1989, ISBN: 0-8247-8000-0.
[17] Fritz R. Walther, Elizabeth C. Haber and Gerald A. Grau, Gazelles and Their Relatives: A Study in Territorial Behavior. William Andrew (January 14, 1984).ISBN-10: 0815509286.
[18] B. O. Koopman, Search and Screening. General Principles with Historical Applications.Pergamon, 1st edition, June 1980.ISBN-10: 0080231357.
[19] Tamil Nadu Forest Department, Vallanadu Blackbuck Sanctuary. (http://www.forests.tn.nic.in/wildbiodiversity/ws_vbs.html)
[20] K.R.Christian,M.Freer,J.R.Donnelly,J.L.Davidson and J.S.Amstrong, Simulation of grazing systems, Centre for Agricultural Publishing and Documentation, Wageningen, the Netherlands, 1978. ISBN 90-220-0645-X.
[21] John F Vallentine, Grazing Management, Acedemic Press Inc, 1990. ISBN 0-12-710000-8.
[22] Udo W Pooch and James A Wall, Discrete Event Simulation – A Practical Approach, CRC Press Inc, 1993. ISBN 0-8493-7174-0.
[23] Philo Juang, Hidekazu Oki, Yong Wang, Margaret Martonosi, LiShiuan Peh, and Daniel Rubenstein, "EnergyEfficient Computing for Wildlife Tracking: Design Tradeoffs and Early Experiences with ZebraNet",ASPLOS-X October 2002, San Jose, CA.
[24] Cynthia L Miner, Valerie Rapp, Frank Vanni and Pilar Reichlein, "Elk, Deer and Cattle: The Starkey Project",Pacific Northwest Research Station - Science Update, Issue 13, March 2006.
[25] Radhika Ranjan Roy, "Handbook of Mobile Ad Hoc Networks for Mobility Models”, Springer 1st Edition, October 2010, ISBN-10: 1441960481.
[26] Alan V. Oppenheim , Alan S. Willsky with S. Hamid Nawab, "Signals and System", Prentice Hall of India 1998, ISBN 81-203-1246-5.
[27] Hsin-i Wua, Bai-Lian Li, Timothy A. Springer and William H. Neilld, "Modelling animal movement as a persistent random walk in two dimensions: expected magnitude of net displacement",Elsevier Science B.V, Ecological Modelling, Volume 132, Issues 1-2, 30 July 2000, Pages 115-124.
[28] Richard H. Barnett and Sarah Cox, "Embedded C Programming and the Atmel AVR", Thomson Press Ltd 2008, ISBN-10: 8131506673.
[29] Laveen Sundararaj, Palanisamy Vellaiyan. “An Overview of Alagappa University Delay Tolerant Water Monitoring Network”. International Journal of Computer Science and Network Security, Korea, Volume 10, Number 5, May 2010. ISSN: 1738-7906.

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