Online Heuristics for Monetary-Based Courier Relaying in RFID-Sensor Networks

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Abstract— **In integrated RFID and Wireless Sensor Networks (RSNs), the abundance of wirelessly enabled mobile devices facilitates forwarding data packets. This presents a beneficial alternative to offload transmission from relay nodes to access points. However, there is no incentive for such mobile devices to carry the relaying task. Hence, we introduce heuristics for Monetary-based Courier Relaying (MCR) that incorporates price negotiation for relaying from source nodes to access points via mobile couriers in RSN architectures. Our heuristics employ a threshold price for each packet prior to transmission. Whether to forward the packet to a courier or to directly transmit it to access points depends on a criticalness function, in addition to the courier's charge with respect to the packet's threshold price. We compare our MCR model with other dominant mobile Ad hoc delivery schemes; eliciting its efficiency in terms of energy, cost and delivery rate.**

Keywords- hurestic; integrated architectures; RFID; wireless sensor network; pricings.

I. INTRODUCTION

The term Internet of Things (IoT) incorporates objects that are able to interact directly with local neighbours within small separate networks. We define an IoT-based topology to have: a) Ability to identify b) Seamless integration c) Ubiquitous connectivity and d) Delay-tolerance. Radio Frequency Identification (RFID) and Wireless Sensor Networks (WSNs) are considered to be the key technologies characterizing IoT [1], forming an integrated model known as RFID-Sensor Networks (RSNs). RSNs represent a heterogeneous platform enabling an abundance of applications into the IoT context. The exploitation of this platform will result in more functional, scalable and cost-effective systems.

Most of the proposed integrated architectures in the literature are application-specific and fail as well in efficiently utilizing the ubiquitously available components in today's wireless topologies.

In this paper, we build upon our work in [2] and [3] to introduce a set of heuristics defining an online implementation of a Monetary-based Courier Relaying (MCR) scheme for price negotiation and data forwarding in RSNs. Our heuristics are built upon the following core parameters:

- *Price* as a parameter composed of two components. The first is *courier price* (P_{CN}) with respect to each courier node. The second component is *price threshold* (τ_p) per data packet; reflecting how much the source is willing to pay for its delivery either via couriers or through direct transmission.
- *Data criticalness* (C_{data}): A binary parameter assigned to each packet based on two RSN attributes: identity and sensed readings. Data with higher C_{data} are better qualified for being forwarded via more costly options.
- *Linger time* (T_{linger}) is the residence time period for each courier entering the transmission range of a source node. T_{linger} is calculated according to the courier's reported trajectory. This, combined with τ_p, will dictate if a courier is considered for relaying.
- *Energy (E)*. If a packet is to be forwarded to a courier, minimum energy is calculated based on T_{linger} in order to minimize energy lost on transmission. In addition, The available courier's energy is proportional to P_{CN}.

We note that none of the proposed RSN architectures in the literature address all the aforementioned parameters for IoT-based topologies. Corresponding solutions seldom handle pricing issues for relaying couriers. Furthermore, Ad Hoc data delivery schemes do not cater for the heterogeneity of couriers' in terms of transmission standards, nor do they differentiate between types of data in terms of generation rate and priority.

To this point, our contributions can be listed as follows:

- We introduce online heuristics detailing the mechanism of our (MCR) scheme in an integrated RSN architecture. Our scheme aims at enhancing delivery while conserving the system's energy by relieving RRs from a portion of its relaying load.
- We present a dynamic assignment of relaying price via intermediate couriers. I.e. MCR allows each courier to arbitrarily decide its current "charge" for forwarding a data packet to a specific destination. Our pricing model caters for heterogeneity stemming from transmission limitations of couriers.
- We compare our MCR scheme to other well-known mobile Ad hoc delivery proposals to show its efficiency in terms of energy consumption and delivery

The rest of this paper is organized as follow: Section II surveys related work on integrated architectures and online relaying schemes. Section III describes our system models and problem statement. Section IV provides the details of our heuristics. Section V evaluates the performance results of our approach in comparison to other integration schemes. Finally, Section VI concludes this paper.

II. Background

In this section, we elaborate on proposed RSN integration approaches. We also overview predominant relaying schemes in Ad hoc networks which resemble IoT in many aspects including node heterogeneity, mobility and infrastructures nature.

A. RSN architectures

RSN architectures may follow several integration approaches, depending on the utilization purpose of their RFID and WSN components. Adding sensing capabilities to RFID tags (ST integration) is a common approach [4]. However, this architecture suffers from doubling the load on the integrated node which is required to run two wireless protocols. This will increase the system's operational and design costs in large-scale deployment. The authors in [5] introduce a prototype system for asset tracking that integrates RFID readers with sensor nodes (SR integration). This architecture includes also simple RFID tags in addition to a base station. We argue, however, that integrating RFID readers with sensors is not a cost-effective approach considering the limited sensing ranges and power resources of sensors, in addition to the high cost of reader deployment on such a wide level. A third integration approach allows RFID tags and sensor nodes to coexist in the same network as distinct devices that are operating independently. The authors in [6] proposed an architecture in which gateways are integrated with RFID readers, while sensors are integrated with RFID tags. Al-Turjman et al. [7] proposed a variant level of integration incorporating RFID reader and relays together in one reader- relay (RR) entity. This aims at concentrating the system's cost complexity in a single component of the architecture while dedicating light nodes (i.e. tags and simple sensors) to data collection tasks and relieving them from any relaying load.

In the RSN architecture we adopt here, we apply integration over two levels according to both ST and RR approaches, as will be elaborated upon in the network model section.

B. Online relaying schemes

Conducting a reliable and timely online relaying in highly dynamic networks is of utmost importance. Most existing Ad hoc relaying protocols are vulnerable to node mobility, especially in large-scale IoT-driven topologies. Traditional topology-based MANET delivery protocols, such as NRRA and AODV [8] rely on presetting end-to-end routes prior to data transmission. Thus, they are vulnerable to mobility.

Moreover, if the path breaks, non-delay-tolerant data packets will be dropped causing a severe deterioration in delivery rates. Another problem that faces dynamic relaying approaches is redundant delivery. Broadcasts cause multiple receptions of the same source-generated packet. Yet, since retransmissions are often used as backups to enhance the system's robustness, many opportunistic routing schemes adopt multicast-routing strategies. Nevertheless, such schemes mostly use link-state topology databases to select and prioritize forwarding candidates. This is impractical for highly dynamic mobile environments since it adds to the transmission load by requiring reception acknowledgments; which are hard to back-trace due to intermittent paths.

Our proposed relaying approach adopts an opportunistic delay-tolerant approach that may utilize mobility of CNs known to be targeting a given destination. This approach does not require exchange of routing tables nor does it consider end-to-end path details as long as CNs are affordable by RRs.

III. System Models & Problem Statement

In this section we describe the network, pricing and criticalness models that are the basis of our MCR heuristics. We then present our problem statement and the assumptions related to it.

A. Network Model

Fig. 1 illustrates the basic blocks of our RSN architecture upon which our MCR heuristics are based. It incorporates:

- Light sensor/tag nodes represented by RFID tags and simple sensor nodes, each dedicated to performing their own protocols; separately or as integrated (ST) entities.
- Integrated Reader/Relay (RR) nodes [7] that perform the combined roles of RFID readers and wireless relays to APs, simultaneously. RRs represent the most complex component of our architecture.
- Courier Nodes (CNs) represented by ubiquitous densely distributed mobile devices in the topology. A CN is presumably moving towards or residing within the communication range of an RR. CNs may be utilized as paid relays between RRs and APs.

The aforementioned hierarchy aims at relieving RRs from a portion of relaying cost, in terms of energy wasted on direct long-range transmission. I.e. if a packet may be delivered to an AP via a CN, with the benefit of reserving RR resources for more *critical* packets, then this option may be realized for a monetary value paid to the CN. Our architecture assumes a connectionless topology, where RRs are not aware of the final status of forwarded packets. In addition, CNs do not exchange data intermediately in our model. Instead, we assume that due to high deployment density, there will be at least one CN that will have a destination matching the RR requirement, or another intermediate RR as a destination. Otherwise, the source RR will directly transmit the packet. CN price is determined by factors related to the CNs resources, as elaborated on next.

B. Pricing model

We propose a decentralized pricing approach where each

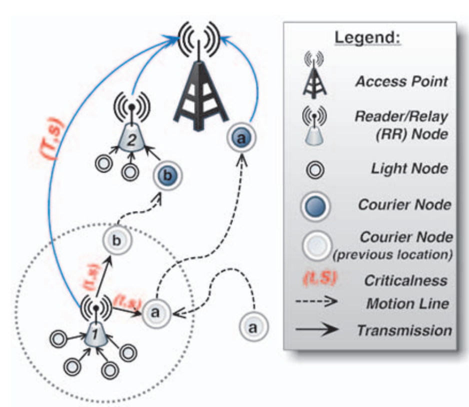

Figure 1. Components of RSN integrated architecture.

CN decides on its service price (P_{CN}); a tradeoff of relaying for a monetary value based on the availability of its own resources. We specify four main parameters for each CN to announce its (P_{CN}) in reply to an RR's relaying request:

- *Delivery time (T_d)*, a combination of the time the CN is on transit (T_{travel}) and its pause time (T_p) such that:
$$T_d = T_{travel} + T_p \quad (1)$$
Where (T_p) is an averaged value calculated for each CN, reflecting the frequency and length of pauses along its announced path:
$$T_p = \#\ of\ stops/trip \times avg\ duration/stop \quad (2)$$
Hence, we define a normalized T_d as:
$$T_d{}' = \frac{T_d}{\max\_T_d} \quad (3)$$
- *Buffer capacity (β)*: Couriers need to buffer packets for variable durations of time until an offloading opportunity arises. The CN's capability of buffering is inversely relates to its service price. We define a normalized buffer capacity for the set of CNs as:
$$\beta' = \frac{\beta}{max\_\beta} \quad (4)$$
- *Transmission capacity* (T_x) represents the transmission range each CN has. We normalize this parameter as:
$$Tx' = \frac{Tx}{max\_Tx} \quad (5)$$
- *Energy (E):* We adopt the general energy consumption model proposed in [9], in which energy consumed for receiving a packet of size *S* is:
$$E_{Rx} = S\gamma \quad (6)$$
whereas the energy consumed for transmitting a packet of size *S* for distance *d* is:
$$E_{Tx} = S(\varepsilon_1 + \varepsilon_2 d^{\delta}) \quad (7)$$
where γ, ε_1 and ε_2 are hardware specific parameters of the utilized transceivers, and δ is the path loss exponent. Based on Eqs. (6) and (7), in addition to knowing the initial energy E_i of each node with its relative position to other nodes, we can calculate the remaining energy E_r per node after the completion of each operational round by:
$$E_r = E_i - TE_{Tx} - RE_{Rx} - AE_a \quad (8)$$
where *T*, *R* and *A* are the arrival rates of transmitted, received and aggregated packets per operational round, respectively, that follows a Poisson distribution, and E_a is the energy consumed for a single packet aggregation.

Based on the four aforementioned parameters, we propose a pricing function for each CN such that:
$$P_{CN} \propto \frac{Tx'}{\beta'\, T_d'\, E_r} \quad (9)$$
It is worth noting that the other price component (τ_p) is not related to the CNs. Rather, it is calculated at each RR per data packet such that:
$$\tau_p = P_{fc} + (P_{Tx} \times S) \quad (10)$$
where P_{fc} is a flat charge, P_{Tx} is the transmission price per byte and *S* is the packet size in bytes. Each packet will be assigned a price-limit directly proportional to its *criticalness*,

C. Data Criticalness Model

As previously mentioned, (C_{data}), is a binary function resulting from the disjunction of sensed data and its ID. According to our RSN architecture, each RR will receive data from light nodes that are either tags, sensors, or combined ST nodes. The reader component of each RR will maintain a list of *important* tags whose detection will mark a critical-tag instant (C_t) (e.g. a VIP vehicle or a lost individual entering the premises). As for sensor nodes, criticalness of sensed data (C_s) is determined at sensor level by:
$$C_s = \theta \times Normalized\ Sensed\_Data \quad (11)$$
where θ is a weighted factor that defines the criticalness of the sensed data based on average reading (e.g. extremely unusual temperature reading) or on spatial/temporal parameters (e.g. motion sensors triggered at a store after operation hours, or high Carbon Monoxide levels sensed within a residential area). In such instances, sensors send their readings to the relay component of RRs marked as critical. Accordingly, an RR will determine the criticalness of a data packet according to the conjunction function:
$$C_{data} = C_t + C_s \quad (12)$$
The criticalness of each data packet is hence determined with respect to a criticalness threshold τ_c maintained by each RR to decide if the packet is worth paying τ_p, or if a less costly courier will do so. These scenarios are depicted in Fig. 1 where immediate transmissions from RR_1 to the AP are labeled with a high C_t, whereas transmissions with low criticalness are relayed via CNs *a* and *b*, to the AP and RR_2, respectively.

D. Problem Statements and Assumptions

Our online heuristics will adopt a data transfer scheme aiming towards solving the following problem:

In an IoT-based topology of high density RRs and CNs, based on the criticalness of the data, each RR is to find best choice of CNs to relay its data packets prior to attempting to directly transmit to an AP.

Based on the above statement, we assume that RRs are stationary and optimally deployed to cover all sensors and tags in its vicinity as discussed in [2]. Each RR will periodically send a beacon announcing its location and the destination of its packet(s). A CN will acknowledge the beacon only if it is willing to participate in data transfer by announcing its P_{CN}, speed (V_{CN}), trajectory (J_{CN}) and final destination(s) (Dst_{CN}). The decision of utilizing any CN is left to the RR depending on the best it can get at a given point of time, not necessarily the overall optimal values among all CNs. All the aforementioned assumptions are necessary in order to realize our MCR models and the corresponding transmission heuristics as follows next.

IV. MCR Heuristics

In addition to the aforementioned model parameters, we define the following parameter for our for price negotiation:

- *Handshake duration* (T_{hs}): Time required to exchange acknowledgements between the RR and the CN.
- *Beacon interval* (T_b): Time an RR will wait for until retransmitting its beacon packet again.
- *Timeout* (T_{out}): Total time the RR will wait until a given packet is carried by any CN before transmitting it directly to the AP with a price equivalent to τ_p. This parameter depends on the criticalness of the packet.
- *Transmission time* (T_{tx}) is set by the transceiver's

technology (e.g. WiFi, blue tooth, 4G, etc.) where:

$$T_{tx} \ \alpha \ \frac{packet\_size}{data\_rate} \tag{13}$$

Algorithm 1 dictates the steps implemented by a given RR_i that has a data packet to be transmitted with a threshold τ_p. The value of τ_p is set in line 6 along with the packet's T_{out}. If the data is critical then it is directly transmitted to the AP (lines 7, 8). Otherwise, the RR will broadcast a beacon to CNs that includes its location, message size and message destination and waits for reply (lines 12, 13). Algorithm 2 dictates the steps taken by CN_j that receives either a beacon or an accept message from *RRi*. If the CN receives a beacon (line 10) then it will check if the message's destination matches one of it announced destinations (lines 11-14). The values of P_{tx} and P_{CN} are sent to the RR which will compare them against τ_p according to Algorithm 1. If an acknowledging message is received from the RR then its data load is transmitted to CN_j. And the CN will accordingly charge RR_i in exchange for its relaying service (Lines 21-23).

V. Performance Evaluation

Our packet-level simulations are run using mobile Ad hoc networks of 1000 nodes under a nominal bit rate of 2 Mbps. Mobile terminals move with a speed that is uniformly distributed between 0 and 120 km/hr. In addition, mobility level is inversely proportional to pause periods that vary according to different traffic sources. Mobility, with varying velocities, and rest instances were restricted for all nodes within a rectangular 150km × 30km grid. Experiments were run for pause periods of 100, 200, 300, 400, 500, and 600 seconds in case of 1000 nodes. Communication was constrained to a range of 200m. A CSMA technique with collision avoidance (CSMA/CA) was used to transmit packets [10]. The simulations use 100 and 500 traffic sources and a packet rate of 4 packets/sec. The T_{out} timer for MCR is set to 10ms.

Algorithm 1: RR seeking CN to relay data load

1. **Function** ***RR*** **( )**
2. **Output:**
3. *Accept_msg*: CN_j has been selected for relying
4. *Ignore*: CN_j has been rejected
5. **Begin**
6. **Initialize** $P_{CN}, V_{CN}, J_{CN}, \tau_p$ *and* T_{out} on current data packet
7. **If** C_{data} **then**
8. Directly transmit to AP
9. **Ignore** //reject courier
10. **Else**
11. **Do**
12. Broadcast beacon
13. **Wait** (T_b)
14. **If** *Ack* received AND $P_{CN} < \tau_p$ **then**
15. **Return** (Accept_msg) //assign packet to CN_j
16. **While (**not T_{out}**)**
17. **If** not assigned **then**
18. Directly transmit to AP
19. **Ignore** //reject courier
20. **End**

Algorithm 2: CN willing to relay packet from RR

1. **Function** ***CN*** **(msg)**
2. **Input:**
3. *msg*: A message from $\boldsymbol{RR_i}$ which is either a beacon or acceptance a s a courier.
4. **Outputs:**
5. P_{CN}, V_{CN} , J_{CN} , Dst_{CN}
6. *Ack*: An acknowledgement in response to RR's beacon
7. **Begin**
8. **Initialize** T_d and P_{tx} *of* CN_j
9. **Receive** (msg)
10. **If** msg = = beacon from $\boldsymbol{RR_i}$ **then** //Where i ≠j
11. Compute T_{linger} in $\boldsymbol{RR_i}$'s vicinity
12. **If** ($T_{linger} > (T_{hs} + T_{tx})$ **AND**
13. ($Dst_{RRi} \in \{Dst_{CNj}\}$ **OR**
14. $\boldsymbol{RR_j} \in \{Dst_{CNj}\}$)) **then** //CN meets other RR
15. **If** J_{CN} satisfied **then**
16. **Wait** for min. ***E*** position
17. **Else**
18. Transmit immediately
19. **send** P_{Tx} and send to $\boldsymbol{RR_i}$
20. **Return** *Ack* with (P_{CN})
21. **If** *msg* received **then**
22. Rx_packet ($\boldsymbol{RR_i}$)
23. Charge $\boldsymbol{RR_i}$
24. **End**

A. Performance Metrics

Two key performance metrics were evaluated: (1) *Packet delivery* fraction; representing ratio of data packets delivered to the destination to those generated by the MCR sources, which reflects the degree of reliability of the routing protocol; (2) *Average energy consumed* measured in milli-joules per byte. It includes all possible energy consumptions caused by transmission at the RRs, receiving at the CNs, retransmission at the CN, and receiving at the APs. Energy may be viewed as a cost factor as well. We use this metric to sow the quality of MCR in choosing better priced solutions. In our simulations, we compare MCR to AODV and NRRA. Ad hoc On-demand Distance Vector (AODV) maintains routes as long as they are needed by the sources. If a source node moves, or a hop on end-to-end route becomes unreachable, route discovery from the source to the destination must be reinitiated. Alternatively, New Reliable Routing Algorithm (NRRA) chooses a stable path for nodes mobility by considering nodes position/velocity information.

B. Simulation Results

Figures 2, 3, 4 and 5 represent the results of our simulation that compares our MCR relaying scheme against AODV and NRRA in terms of packet delivery percentage and average energy consumed per measured in milli-joules per byte. Both metrics are compared against pause time T_p which is used here as a metric of mobility in the network. In Fig. 2, we see that MCR maintains the lowest energy consumption among the three schemes as the T_p value increases for a topology of 100 source nodes. This is also true as the number of sources increases to 500 nodes (Fig. 3). This is expected since MCR heuristics utilize a pricing function that incorporates transmissions; either immediately to the APs of via CNs based minimum energy consumption. Fig. 4, represents the performance of the three schemes in terms of delivery fraction compared to T_p for 100 sources. Again, MCR performs better than the two rival schemes and does so as the number of sources raises to 500 (Fig. 5). This is due to the transmission function (Eq. 9) that better rewards couriers with lower T_d (which incorporates T_p according to Eq. 1). This maintains the delivery rate of MCR as the number of sources increase. While that same increase has a deteriorating effect on AODV, for instance, which suffers from a 13% drop in its delivery rate.

VI. CONCLUSION

We introduce heuristics for monetary-based courier relaying (MCR) that governs packet relying and price negotiation in RSNs. Our scheme incorporates a criticalness function involving both ID and sensory attributes of the packets; with respect to its spatial and temporal properties. The decision to forward the packet to a courier depends on the criticalness bound to it, in addition to the courier's charge with respect to a packet's threshold price set by the RR. Hence, direct transmission to access points may be considered if packet criticalness is high, or if no feasible courier is available. We compare our RSN scheme to other dominant mobile Ad hoc delivery schemes such AODV and NRRA in terms of energy consumption (cost) and delivery rate. Our simulation results show that MCR performs superiorly under varying topology settings in terms of nodal count and mobility.

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REFERENCES

[1] M. Zorzi, A. Gluhak, S. Lange, A. Bassi, "From today's INTRAnet of things to a future INTERnet of things: a wireless- and mobility-related view," IEEE Wireless Comm., vol. 17, no. 6, pp.44-51, Dec. 2010.

[2] F. Al-Turjman, A. Al-Fagih, W. Alsalih and H. Hassanein, "A delay-tolerant framework for integrated RSNs in IoT," Computer Communications: 10.1016/j.comcom.2012.07.001. Available online 11 July 2012.

[3] A. Al-Fagih, F. Al-Turjman and H. Hassanein, "Ubiquitous robust data delivery for integrated RSNs in IoT," IEEE Global Comm. Conference (GLOBECOM 2012), Anaheim, California, 3-7 Dec. 2012 (Accepted).

[4] A.G. Ruzzelli, R. Jurdak, and G.M.P. O'Hare, "On the RFID wake-up impulse for multi-hop sensor networks", 1st ACM Workshop on Convergence of RFID and Wireless Sensor Networks and their Applications, Sydney, Australia, 2007.

[5] A. Mason, A. Shaw, A.I. Al-Shamma'a, "Asset tracking: beyond RFID," 7th Annual PG Symposium on the Convergance of Telecommunications, Networking and Broadcasting, pp. 267-272, 2006.

[6] L. Zhang, and Z. Wang, "Integration of RFID into wireless sensor networks: architectures, opportunities and challenging problems", Intl. Conf. on Grid and Cooperative Comp. Workshops, Changsha, Hunan, pp. 463-469, 2006.

[7] F. Al-Turjman, A. Al-Fagih and H. Hassanein, "A novel cost-effective architecture and deployment strategy for integrated RFID and WSN systems," 1st IEEE Intel. Conf. on Computing, Networking and Comm., Maui, Hawaii, 2012, pp. 835-839.

[8] J. Broch, D.A. Maltz, D.B. Johnson, Y.C. Hu, and J. Jetcheva, "A performance comparison of multi-hop wireless ad hoc network routing protocols," ACM MobiCom, pp. 85-97, 1998.

[9] K. Xu, H. Hassanein, G. Takahara, and Q. Wang "Relay node deployment strategies in heterogeneous wireless sensor networks," IEEE Trans. on Mobile Computing, vol. 9, no. 2, pp. 145-159, Feb 2010.

[10] IEEE Standards Dept. Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, IEEE standard 802.11, 1997.

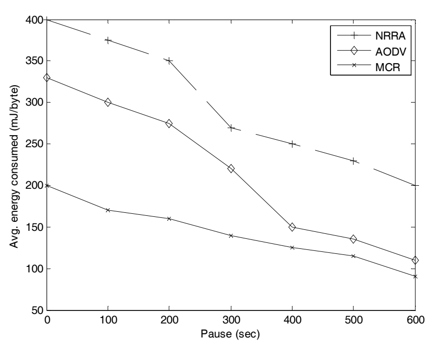

Figure 2. Energy consumed vs. pause time for 100 sources

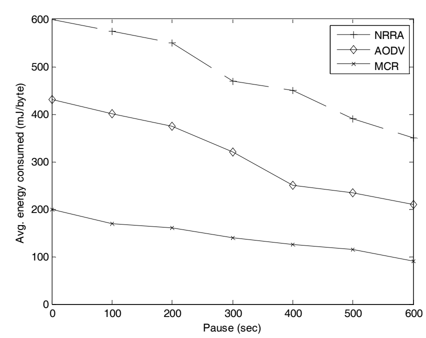

Figure 3. Energy consumed vs. pause time for 500 sources

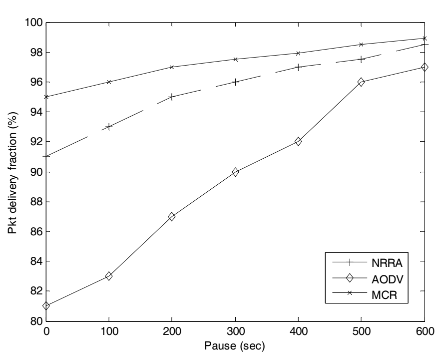

Figure 4. Delivery fraction vs. pause time for 100 sources

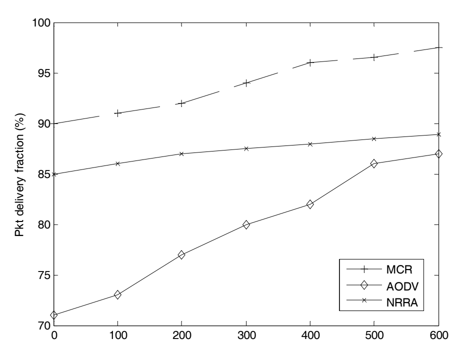

Figure 5. Delivery fraction vs. pause time for 500 sources