

# APPLYING LOAD BALANCE TO REDUCE THE ENERGY CONSUMPTION OF THE VIRTUAL ROUTING PROTOCOL

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Abstract: Energy consumption is a key issue in mobile ad hoc networks. To reduce the energy consumption of the network interface, it is necessary to turn it off, immediately affecting the routing protocols. Therefore, routing protocols and energy saving algorithms must be designed to work within each other. This article presents the use of energy management, using the load balance technique with single path, over the Virtual Routing Protocol (VRP). VRP is a hybrid routing protocol that can achieve a high delivery ratio, though it has a high energy consumption. Using load balance, it is possible to minimize this drawback, while keeping the high delivery ratio from VRP. It is shown that the basic VRP consumes more energy than AODV and DSR. While using the load balance technique, the energy consumption of VRP becomes very similar to AODV and DSR.

## 1 INTRODUCTION

The Virtual Routing Protocol (VRP) (Albini et al., 2006) is a hybrid routing protocol for MANETs, which uses a *virtual structure* to route packages. The virtual structure defines the proactive part of the protocol, i.e. a connection from unit  $u$  to unit  $v$ , in the virtual structure, means that unit  $u$  must maintain an updated route to reach unit  $v$ . Unit  $u$  is called a *scout*, and each scout is responsible for maintaining routes to a small subset of other units (called *peers*). Figure 1 exemplifies a virtual structure for VRP.

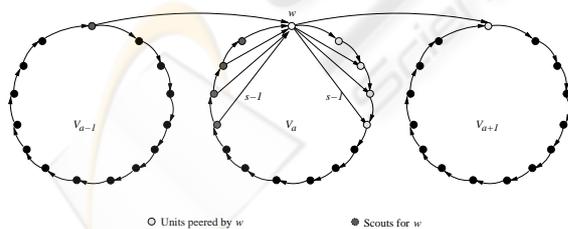


Figure 1: Virtual Structure Example.

The use of the virtual structure makes VRP able to maintain a high delivery ratio (Albini et al., 2006). Another protocol, called Virtual Distance Vector (VDV) (Robba and Maestrini, 2007), also employs a virtual structure, but the goal of VDV is to reduce the delay to build a route between any source-destination pair. Though both protocols use the same virtual

structure concept, they are quite different: VRP is based on source routing and achieves a high delivery rate, while VDV is based on distance vectors and achieves a small delay to build routes. However, they are very similar in one point: they use more energy to achieve their goals when compared to AODV (Perkins and Royer, 1999) and DSR (Johnson and Maltz, 1996), the two major distance vector and source routing based routing protocols for MANETs. Figure 2 compares the network lifetime for AODV, DSR and VRP.

Energy consumption is critical in MANETs (Feeney and Nilsson, 2001), thus saving energy is vital to maintain the network alive as long as possible. It is possible to reduce the energy consumption of hardware components, such as CPU, display, discs and network interface. It is also possible to use some algorithms to turn off the network interface or even keep it in a low energy consumption state most of the time (Cho et al., 2005; Hundewale et al., 2007; Iqbal et al., 2006). Even though turning off the network interface increases the single unit lifetime, it has a direct impact on the routing protocol. Thus, energy aware algorithms and routing protocols must be designed to work within each other (Feeney and Nilsson, 2001).

One possible technique that can be applied on routing protocols to increase the network lifetime is the *load balance* (Cho et al., 2005; Hundewale et al., 2007; Iqbal et al., 2006). Load balance does

not aim to reduce the total energy consumption, but to uniformly distribute it among the entire network. It has two variations, multipath and single path protocols. In multipath load balance, also known as *Multi-Path Routing* (Ziane and Mellouk, 2005; Lee and Gerla, 2001), data messages follow into distinct routes simultaneously from the source to the destination. The multi-path technique can achieve a better load balancing than shortest path routing if the number of paths in use is high (Ganjali and Keshavarzian, 2004). The single path load balance technique consists in finding a *good* route to send data messages from the source to the destination and using it until a better route is found. The great challenge of such technique is to decide when a route is not *good* anymore and a new route must be found and used.

This article describes the application of the single path load balance technique on the Virtual Routing Protocol to reduce its major drawback, the excessive energy consumption. Using such technique on VRP, it is possible to reduce its energy consumption, making it very similar to those of DSR and AODV, without losing its main advantage, the high delivery ratio. All results were obtained through simulations, using GloMoSim and considering the energy consumption model presented in (Feeney and Nilsson, 2001).

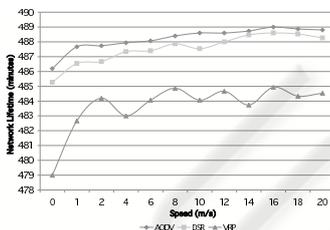


Figure 2: Network Lifetime.

The rest of this article is organized as follows: Section 2 details the application of the load balance technique over the Virtual Routing Protocol; Section 3 describes the modifications made on GloMoSim to simulate energy consumption; Section 4 contains the simulation results and Section 5 draws the conclusions and future work.

## 2 VRP WITH LOAD BALANCE

To use the load balance technique on VRP, it is necessary to change the virtual path construction phase of the VRP. It is essential that VRP chooses the virtual path with the highest residual energy. To do so,

all scouts must know, or at least estimate, the residual energy of the physical routes to their peers.

The residual energy of a physical route from unit  $i$  to unit  $j$ , denoted by  $re_{i,j}$ , is the minimum of the remaining energy of all units in the route. Consider  $Vre_{i,j} = \{e_i = e_0, e_1, e_2, \dots, e_j = e_n\}$  as the vector of remaining energy of all units in the route from  $i$  to  $j$ , then  $re_{i,j} = \min\{e_1, e_2, \dots, e_{n-1}\}$ . Note that the remaining energy of the source  $i$  and the destination  $j$  are not considered.

To compute  $re_{u,v}$  between any scout-peer pair, the Route Reply messages must be changed including a field called *route energy*. When such a message traverses the network, it collects the residual energy of all units in the route. Thus, when it arrives at the scout  $u$ , it knows the residual energy of the route connecting itself with peer  $v$ . This information is maintained within the virtual structure as weights on the edges connecting  $u$  with its peers. It is important to emphasize that weights are kept locally.

Recalling that the main change on VRP is on the virtual path construction, now the virtual path between the source and the destination is not built entirely by the source. To build a route from a source (unit  $s$ ) to a destination (unit  $d$ ) in the new routing protocol, unit  $s$  follows the following steps:

1. If  $d$  is a physical neighbor of  $s$ , then the route is trivial and  $k = d$ .
2. Otherwise, if  $s$  is a scout to  $d$ , then  $k = d$ .
3. Otherwise:
  - (a) Computes the distance between itself and  $d$  in the virtual structure,  $D_{s,d}$ .
  - (b) Finds the unit  $k$  such that  $k \in P_s$  and  $\forall m \in P_s, re_{i,k} > re_{i,m}$ , where  $P_s$  is the set of peers of unit  $s$ .
  - (c) Computes  $D_{k,d}$ . If  $D_{k,d} \leq D_{s,d}$  then chooses  $k$  as the next virtual hop. If  $D_{k,d} > D_{s,d}$ , return to step 3(b) and choose another  $k$ .
  - (d) If  $s$  does not have an up-to-date route to  $k$ , then return to step 3.b and choose another  $k$ .
  - (e) If there is no  $k$  that satisfies steps 3(b) and 3(c), disconsider step 3.b and choose a unit  $k$  which satisfies steps 3(a) and 3(c) only.

After finding unit  $k$ ,  $s$  sends the message to  $k$  through the physical route proactively maintained by itself. When unit  $k$  receives the message, it verifies if it is the destination, if so the protocol ends. If unit  $k$  is not the destination, it repeats the above steps considering itself as the origin,  $s = k$ . This process is repeated until the message arrives at the destination. Note that all units within the physical route between  $s$  and  $k$  behave exactly in the same way as they do in VRP. Re-

calling that VRP uses source routing, i.e., data messages carry the entire route they must traverse, units in the physical route between  $s$  and  $k$  just forward the data message to the next physical hop.

### 3 ENERGY CONSUMPTION ON GLOMOSIM

The *Global Mobile Information System Simulator Library* (GloMoSim) is a simulation environment to wireless networks. In this work, GloMoSim was adapted to include the energy consumption functionality and to stop the message redirection when the battery of the unit depletes. All parameters depicted here are from (Bannack and Albin, 2008).

The energy consumption of each unit is not only related with the network interface, other hardwares like CPU, display or memory contribute to it (Feeney and Nilsson, 2001). When a message is transmitted, it is necessary to process and even store it, consuming energy. Without loss of generality, these values are grouped in a constant  $\Delta$ . Further, the average energy consumed to keep the network interface in idle mode is called  $\delta$ .

The energy used to send and receive a message can be split in the following parameters:

- Send Preparation Phase ( $\Sigma$ ): energy used during send message preparation phase. It includes the encapsulation, the inter-frame times, changing mode on the network interface communication, and sending the 802.11 MAC preamble;
- Send Message ( $\sigma$ ): energy spent to send one byte of the message, headers and data;
- Receive Preparation Phase ( $\Omega$ ): energy used during receive message preparation phase. It includes the decapsulation, the inter-frame times, changing mode on the network interface communication, and receiving the 802.11 MAC preamble;
- Receive Message ( $\omega$ ): energy spent to receive one byte of the message, headers and data.

After each simulated second, the residual energy of the unit ( $\gamma$ ) is decreased by energy consumption value to keep the node and the NIC alive (if there were no transmission / reception on the previous second):  $\gamma_{t+1} = \gamma_t - (\Delta + \delta)$ . If there were a message transmission on the previous simulated second, the residual energy of the unit is decreased by (where  $b$  is the number of bytes sent in this second):  $\gamma_{t+1} = \gamma_t - (\Delta + \Sigma + (b * \sigma))$ . If there were a message reception on the previous simulated second, it is decreased by (where  $b'$  is the number of bytes received in this

second):  $\gamma_{t+1} = \gamma_t - (\Delta + \Omega + (b' * \omega))$ . If  $\gamma_{t+1} = 0$ , the unit is considered unachievable (turned off) by any other unit of the network, and it will not send or receive any message.

The energy consumption model implemented is linear, i.e., the energy used to transmit/receive a message depends only on the message size. When a node does not have sufficient energy to completely send or receive a message, its battery is emptied and the message discarded. The remain energy, before being emptied, is added to the energy used to keep the node alive.

Table 1 (Bannack and Albin, 2008) show the values for each of the above variables to send and receive messages, respectively. These values were obtained using the real energy consumption values of a Compaq WL110 connected to a HP IPAQ 3600.

Table 1: Energy used to send and receive messages.

Parameter	Energy (pWh)
$\Sigma$	44,777
$\Omega$	30,749
$\Delta$	161,507,937
$\sigma$	161
$\omega$	111
$\delta$	113,055,556

## 4 SIMULATION RESULTS

Simulations were made using GloMoSim 2.03 with the modifications specified in Section 3 and in (Bannack and Albin, 2008). All simulations were performed on an Intel Pentium Xeon 3.2GHz, 4GB of RAM, running Debian Etch 4.1.1-21 with kernel 2.6.18-4-686. The network lifetime was measured considering the time from the network initialization until the first unit runs out of battery.

### 4.1 Scenarios

Three different scenarios were evaluated: varying the network density, the maximum speed of the units and the throughput. The common way to vary the network density is to vary the number of units in a constant area, though it is possible to obtain the same results maintaining the number of units constant and varying the network dimensions. Without any impact on the results, the network density was varied by increasing the network dimensions from  $50m^2$  to  $100.000.000m^2$ , while maintaining the number of units and their transmission range constant. The maximum speed of the units was varied from  $0m/s$  to  $20m/s$  and the throughput from 1024bps to

512.000bps for each sender. Besides, all simulations consider the parameters presented in table 2. It is important to point out that the cbr traffic considers 10 sources, sending data packages of 512 bytes to other 10 units, and data packages are sent from the start of the simulation until the first unit of the network runs out of energy.

Table 2: Parameters used in the simulations.

Parameter	Value
UNITS	50
RAIO TRANSMITION RANGE	250m
TRAFFIC	CBR
SIZE OF DATA PACKAGES	512 bytes
SIMULATION-TIME	14H
NODE-PLACEMENT	uniform
MOBILITY	random waypoint
MOBILITY-WP-PAUSE	0
MOBILITY-WP-MIN-SPEED	0
MOBILITY-POS-GRANULAR	0.5
PROPAGATION-LIMIT	-111.0 dBm
PROPAGATION-PATHLOSS	free-space
NOISE-FIGURE	10.0 dBm
TEMPERATURE	300.0 K
RADIO-TYPE	radio-accnoise
RADIO-FREQUENCY	2.4e9Hz
RADIO-BANDWIDTH	11.000.000 bps
RADIO-RX-TYPE	SNR-bounded
RADIO-RX-SNR-THRESHOLD	10.0 dB
RADIO-TX-POWER	7.005 dBm
RADIO-ANTENNA-GAIN	0.0 dB
RADIO-RX-SENSITIVITY	-91.0 dBm
RADIO-RX-THRESHOLD	-81.0 dBm
MAC-PROTOCOL	802.11
PROMISCUOUS-MODE	yes
NETWORK-PROTOCOL	IP
NETWORK-OUTPUT-QUEUE	100

## 4.2 Results

Figures 3, 4 and 5 show the simulation results varying the network density. In these simulations the maximum speed of the units is set to 20m/s and the throughput to 16384bps. In figure 3, it is possible to notice that the network lifetime of VRP with load balance is very similar to the lifetime of AODV and DSR, while the network lifetime when using VRP is much smaller. Further, the energy necessary to deliver a single data package (Figure 4) is much smaller when VRP with load balance is compared with the original VRP. Indeed the energy used by VRP with load balance is almost the same as DSR and AODV. Figure 5 depicts only the energy used by the routing protocol to deliver each data message. Even in this case it is possible to notice that the load balance technique reduces the VRP energy consumption.

Figures 6, 7 and 8 depict the results varying the maximum speed of the units. Even though figure 6 shows that DSR and AODV still have a better network lifetime, the use of load balance on VRP significantly increases the network lifetime. This shows that the load balance was able to find a route with more residual energy, thus saving the units with less energy from participating in the routing process.

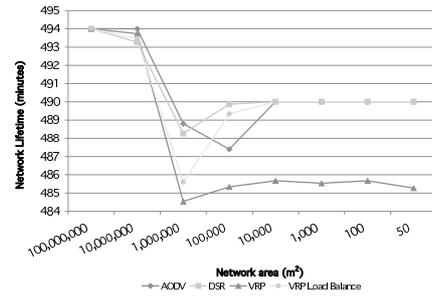


Figure 3: Network density: network lifetime.

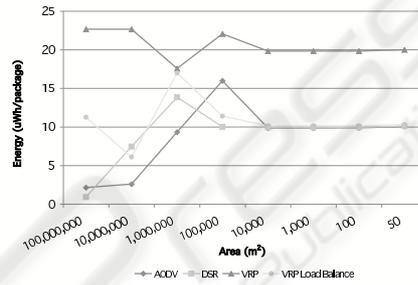


Figure 4: Network density: total energy to deliver a data message.

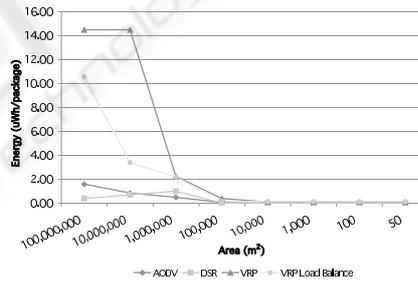


Figure 5: Network density: energy used by the routing protocol to deliver a data message.

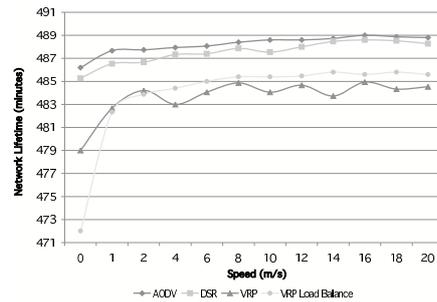


Figure 6: Maximum speed: network lifetime.

The energy necessary to deliver a data package (Figure 7) is higher in VRP due to the overhead caused by the routing information sent within the data package and by the need of constant proactive scout update. In spite of that, the use of load balance over

the VRP increases the network lifetime specially to speeds over 4m/s. Note that the energy used exclusively by the routing protocol messages to deliver a data message (Figure 8) is not influenced by the use of load balance. This shows that the load balance technique was able to select better routes, i.e., routes with more residual energy.

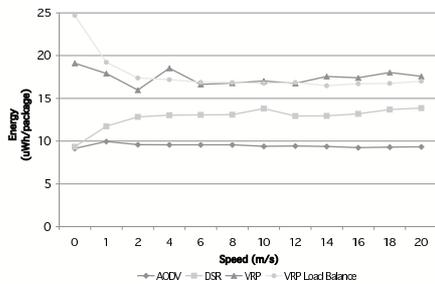


Figure 7: Maximum speed: total energy to deliver a data message.

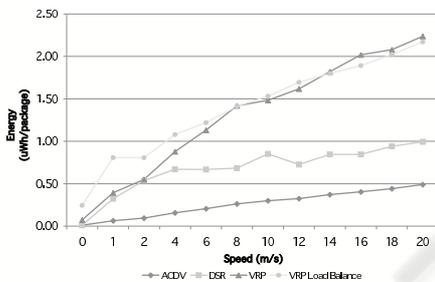


Figure 8: Maximum speed: energy used by the routing protocol to deliver a data message.

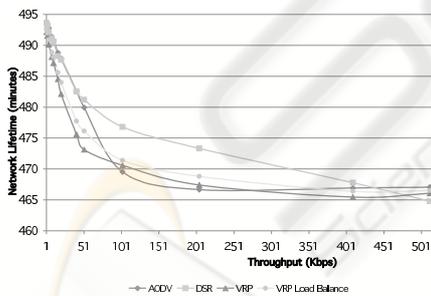


Figure 9: Throughput: network lifetime.

Figures 9, 10 and 11 show the simulations results while varying the throughput of the network. In Figure 9, it is possible to notice that the use of load balance increases the network lifetime of VRP and it is able to maintain the gain even in high traffic conditions. Besides, the use of load balance made the results of VRP very similar to the ones of DSR and VRP, independently of the throughput. Furthermore, the energy necessary to deliver data package (Figure 10) is practically the same for VRP with bal-

ance and AODV and DSR, all these without changing the energy used exclusively by the routing protocol messages (Figure 11).

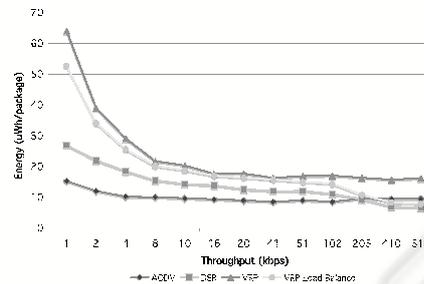


Figure 10: Throughput: total energy to deliver a data message.

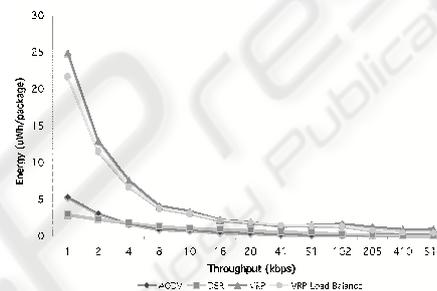


Figure 11: Throughput: energy used by the routing protocol to deliver a data message.

## 5 CONCLUSIONS AND FUTURE WORK

Routing and reducing the energy consumption are two of the most critical challenges of a mobile ad hoc network. Furthermore, both tasks are interdependent, as turning off the network interface to save energy, routing protocols are immediately affected. Therefore routing protocols and energy saving algorithms must be designed to work within each other.

A technique to save energy without turning off the network interface of the units is the load balance technique. The load balance technique is applied to the routing protocol, which must avoid the use of units with low residual energy. The use of the load balance technique might distribute the energy consumption uniformly over the network, thus maximizing the network lifetime without turning off any network interface. This article applies the concept of load balance to the Virtual Routing Protocol. The Virtual Routing Protocol is a hybrid routing protocol for MANETs, which uses a virtual structure to route packages over the network.

Applying the load balance technique to the Virtual Routing Protocol, it is possible to increase the network lifetime, without a significantly impact on the delivery ratio. As shown, the energy used exclusively by the routing protocol messages to deliver a data message is not influenced by the use of load balance. This shows that the load balance technique was able to select better routes, i.e., routes with more residual energy, to send data messages.

Future work includes the study of the load balance technique over the Virtual Distance Vector, to verify if it is possible to achieve the same gain without losing its major advantage, a very small delay to build a route. It also includes the study of the applicability of the load balance with multiple paths on the Virtual Routing Protocol and the Virtual Distance Vector.

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