A Resilient DAP Dynamic Selection Algorithm Based on Quality Aware Metric for Smart Grids

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***Abstract*—Smart Grids are the evolution of the current electric system to meet the challenge of increasing demands for energy in this century by integrating the electric grid with data communication network. The challenge of this network is to fulfill safety requirements: reliability and resilience required in order to meet various types of services and applications. The use of wireless mesh networks can provide scalability and resilience to this communication network, but there are challenges that need to be evaluated and analyzed so that it is in fact a solution for communications in Smart Grids. This paper proposes an algorithm for dynamic selection of gateways in a multihoming Smart Grid network improving performance when a gateway's fault occurs due to a probabilistic choosing gateways with good metrics. The results indicate that the proposed algorithm makes the routing protocol more robust and resilient against gateway's fault compared to a deterministic algorithm for dynamic gateway selection.**

***Keywords*—reliability, smart grid, wireless mesh networks (WMNs).**

I. Introduction

Basically the current electrical system has an outdated hierarchical architecture that does not meet the future demands of energy consumption due to various limitations such as limited generation capacity, one-way flow of energy (generationtransportdistributionconsumption) and communication, low and deficient communication, the use of fossil fuels in power generation and reliability problems [1]. Modernization the existing electricity grid aims to solve these problems, improving efficiency, reliability and security, integrating the use of renewable energy produced by consumers, making the one-way flow in two-way flow for energy and communication [1], [2]. Two-way communication infrastructure is essential for Smart Grids [3], because it needs to send commands and to receive information from its components and sensors in real time, with reliably, allowing monitoring, maintenance and control of the entire grid.

Smart Grids require two-way communication that has specificities of delay, bandwidth, frequency of updates, reliability, security and time response for each distinct application in their different fields [3]. Advanced Metering Infrastructure (AMI) is fundamental and the first step to realize a Smart Grid[4], [5]. Your security requirements should provide robustness and resilience to prevent or recover from cyber attacks or problems caused by interference, providing the stability and reliability to AMI communication. This communication may use available wired or wireless technologies that support the exchange information between components of AMI [6], [7]. Different types of technologies can be used: cellular technology [8], WiMAX, ZigBee [8], RF Mesh [9], IEEE 802.11-based Wireless Mesh Networks (WMN) and PLC [10].

PLC (*Power Line Communication*) is the most used wired technology [6], but has limitations. In case of failures, such as physical disruption of power lines, would not be possible to maintain communication between AMI components [11]. Wireless networks offer more benefits than wired networks such as lower cost, ease of deployment and the available signal in a large area [8]. Among all wireless technologies WMN has advantages compared to single-hop infrastructure network architecture, because it communicates in multi-hop way that extends the coverage of the network and allowing communication with alternative paths in case of failures in links [9], [12].

The challenge is to adapt WMN to communication requirements required by AMI, where hundreds of meters communicate with Utility's head-end through DAP (Data Aggregation Point), which are the gateways of this network. This large number of nodes is the main challenge for the WMN [13], since more than 100 meters may be associated to one DAP. If they send data simultaneously should cause congestion to the network. A way to reduce this problem is the use of multiple DAP. There are other problems related to the propagation conditions of the external environment that provide attenuation, interference and variation to the signal strength [3]. The routing protocol must be able to find reliable routes to improve performance and meet the requirements of AMI network.

The new wireless communication devices have the capacity to operate in different transmission rates and are sensitive to propagation conditions generating another challenge for routing and its metric. The latter should take into account the fluctuations of link quality and transmission rate for consistent assessment of costs.

Given the problems faced by routing protocol in WMN to comply with AMI communication requirements, we propose an algorithm that dynamically selects a DAP for communication between meters and headend. In this problem, we assumed that each meter can connect, through multiple hops, to a set of DAP. The main goal of this algorithm, called Dynamic Selection Algorithm (DDSA), is to increase the reliability, robustness and resiliency using multiple DAP by meters thus improving performance in a presence of DAP's failure, since there is the probability of choosing other DAP for communication with the headend.

The organization of the paper is as follows. In Section II, discloses the particularities of the AMI communication network and its challenges and problems. Section III presents related work. Section IV describes and explains the working principle of DDSA. Section V presents the results obtained in the simulations. Section VI concludes the paper and presents ideas for future work.

II. Background

A. A Brief Overview of AMI

The modernization of the current electricity grid involves a large use of information technology to move the current system towards Smart Grid using communication that allows bidirectional flow of information between the different subsystems and the headend. Nearly 8% of all energy generated is lost along the transmission lines and 20% of the total generation capacity is only to supply peak demands, which represent only 5% of the total demand [1]. About 90% of power outages and disturbances are assigned to distribution subsystem, thus the success of a Smart Grid depends on the deployment of an interconnected distribution subsystem.

AMI is the main application of distribution subsystem that aims to improve the reliability and a change in paradigm to one where customer demand adjusts to the power generation. AMI is basically composed of smart meters, gateways or DAP and Utility's headend, all interconnected by a communication network. The headend is connected to multiple DAPs, which in turn has connections to multiple smart meters. The meters send the measurement data to the headend through DAP and this traffic is characterized by the exchange of short messages.

These messages have a payload that varies from tens to hundreds of bytes and are sent periodically, typically in a 15 minutes interval, and remain inactive the rest of the time [14], [7]. They can be sent in a single data packet originated by meters connected to a DAP. The headend can send commands and requests to meters also through DAP.

B. Problem Statement

According [15], it is necessary for each meter a band from 10 to 100 Kbps and the latency should be less than 2000 ms. Since investments in the power sector are long-lasting, it is desirable that the AMI should also support long-term operations [5]. New necessities for information may arise and making the requirements more stringent such as latency that should be less than hundreds or tens of milliseconds in applications that need information in real time.

The AMI traffic can be classified into regular and on-demand. It's regular when data consumption are automatically sent by the meters at predetermined intervals time [16], [7] and constitute the majority of data traffic flowing through AMI [5]. The on-demand traffic is constituted of alert messages from meters, command and control sent by the headend to meters and DAP and the responses to these commands [16]. In the latter type of traffic can occur a greater increase in network congestion due to the request for sending information, by headend to a large numbers of meters, that would send simultaneously this data. DAP is a single point of failure, because all traffic between meters and headend or vice versa flows through it, a failure in it will stop the entire network from working.

The residential density of the area, which can be a dense urban area or rural area, determines the amount of meters per area, which according to [16] can be classified into rural, suburban or urban scenario, with density varying from 10, 800 or 2000 meters per km^2, respectively. The external environment conditions in combination with the number of meter will determine the level of interference and attenuation in communication between meters and DAP will have. This may cause breaks in routes and loss of performance due to the increase in packet loss and retransmissions [17].

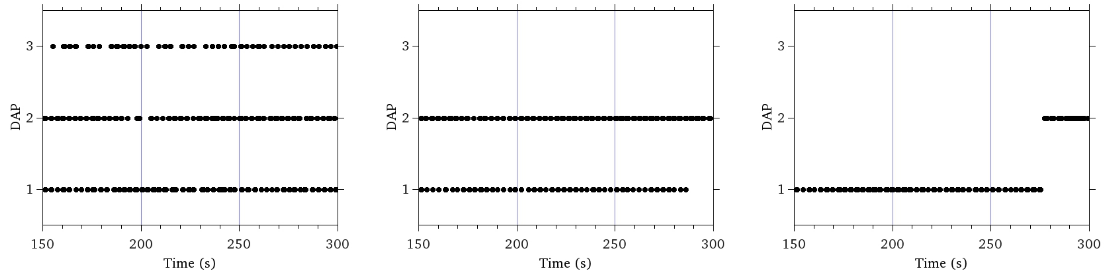
Due to the peculiarities of the AMI network and a large amount of meters acting as routers/clients mesh, there is a possibility of problems with loops and broken route [18], causing a degradation in performance that may lead to a non-compliance with communication requirements. The density of the WMN varies with the number of households in the region which can be dense or a very sparse area. Thus the routing protocol should handle this variation, providing an acceptable level of service regardless of WMN density. Another problem is the increased amount of collisions near the DAP because all packets are routing to it [6].

III. Related Work

The work in [11] proposes the use of WMN in AMI where multiple domains of mesh networks are connected by a WiMAX backbone. This architecture provides redundant paths between meters eliminating problems like nodes failed and route break increasing their resilience and making network fault tolerant. However, as there is only one DAP acting as gateway in each WMN domain, if it becomes unavailable there will be no communication between the meters and the headend. This is the same problem [19], where the WMN consists of meters, routers and collectors. The meters communicate with routers or directly to collectors, the latter controls up to 25,000 meters and routers on a single network.

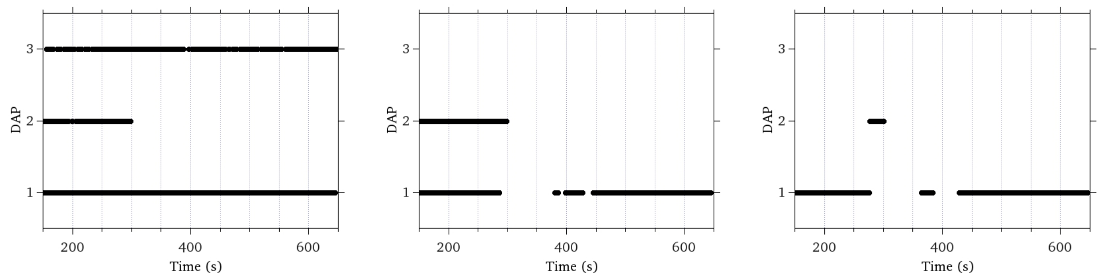
The work in [19] makes use of multiple gateways to increase the WMN resilience, because in addition to providing redundant paths also provides redundancy of gateway. Another work that solves the problem of multiple gateways is [20] which also preserves the gateway output for each connection, but also adds load balancing. These approaches are applied to WMN that serve as the backbone for internet access. In these access networks is common to use the technique NAT (Network Address Translation), which does not exist in AMI, being necessary to preserve the connection with the gateway output and no breakage of TCP connections semantics occur.

The work in [21] and [22] are designed to suit the requirements of AMI networks and make use of multiple DAP for communication between meters and headend modifying the HWMP protocol (Wireless Hybrid mesh Protocol). The work in [22] although solve the problem of discard of the queue, still suffers from other problems such as protocol stability of routes and loops that according to the authors is a characteristic of distributed backpressure system adopted by them. However,



(a) DDSA-30% (b) DDSA-85% (c) Multi-DAP

Fig. 1. DAP's choice by node 16



(a) DDSA-30% (b) DDSA-85% (c) Multi-DAP

Fig. 2. Packets delivered by node 16

neither of them has been evaluated the protocol behavior in an environment with a DAP failure, nor using adaptation of transmission rate, which increases the problem of instability of routes. They use as a base protocol that has scalability problems and congestion caused by control messages [23] making it difficult to use in AMI.

Our proposal DDSA makes use of multiple DAP for communication between meters and headend, and differs from [21] and [22] to be designed to improve performance in environments with DAP failure and also be independent of the routing protocol and metric, and can be implemented in that best suit the implementation of AMI. In DDSA, each new send data, meters probabilistically choose DAP to which the data packet is sent through. Thus, improved performance and network resilience by distributing traffic among the DAP to each transmission, according to the probability of selection of each one, and provide resilience as if one is unavailable, it is possible to choose another.

A. Routing Metrics

MARA (Metric-Aware Rate Adaptation) [24] is a mechanism that joins routing metric with rate adaptation for transmission in WMN through the concept of cross-layer design. It uses statistical information of routing metrics to select the best rate and in turn, based on this choice, the metric can estimate the actual cost of the link. Thus, metrics and rate adaptation share information and make decisions together resulting in better choices of routes by the routing protocol. The calculation of the metric of a link is based on a conversion process in which first is estimated the SNR (Signal-to-noise ratio) from the link success probability of probe packets in a given transmission rate that can be of 1, 18, 36 or 54 Mbps. With this SNR estimation is possible, by means of a probability function loss estimate the PER (Packet Error Rate) to other rates. Its advantage is that it solves the problem that metric and choice of rate are studied separately, although they are strongly related.

IV. DDSA (DAP Dynamic Selection Algorithm)

The principle of the proposed algorithm is based on the calculation of the probability of selecting a DAP using information of routing metric to define a probability selection value to each DAP. Based in this value, it is determined which DAP is used by node and the higher the probability value greater are the chances of a DAP being chosen. The use of multiple DAP increases the reliability and performance of the routing, because it is possible to choose routes to headend using any DAP.

For each DAP d_j is computed the probability $P_{(m_i,d_j)}$ to be selected by the meter m_i and is given by the expression:

$$P_{(m_i,d_j)} = \frac{M_{(m_i,d_j)}}{\sum\limits_{k=1}^{N} M_{(m_i,d_k)}} \quad ,$$

where $M_{(m_i,d_j)}$ is the value of the quality metric of the path (m_i, d_j), which is divided by the sum of all metric values of the meter m_i for all DAP.

To prevent selection of DAP with worse metrics a threshold α is included in the algorithm. To do this, first the best metric is found then is computed its probability to be select. This probability is multiplied by α, that have values between 0 and 1, giving a value that is compared with others DAP probability. If DAP probability is smaller than it then it is discarded. The threshold α is a parameter of the DDSA algorithm that affects the performance and the behavior of network. A lower value of α implies

The algorithm 1 shows how the DAP choice is made for one meter m_i.

input : meter m_i, DAP vector d, number of DAP N, threshold value α
output: $Selected\_DAP$
$Sum \leftarrow 0$
$Prob\_temp \leftarrow 0$
$best\_M \leftarrow 0$
//sum of all metric values and select de best DAP
for $k \leftarrow 1$ **to** N **do**
  $M_{m_i d_k} \leftarrow findMetric(m_i, d_k)$
  $Sum \leftarrow Sum + M_{m_i d_k}$
  if $best\_M < M_{m_i d_k}$ **then**
    $best\_M \leftarrow M_{m_i d_k}$
    $Selected\_DAP \leftarrow d_k$
  end
end
$Prob\_var \leftarrow randomUniform(0, 1)$
$threshold \leftarrow best\_M * \alpha$
//choosing DAP
for $k \leftarrow 1$ **to** N **do**
  if $Prob\_temp >= Prob\_var$ **then**
    break
  end
  $M_{m_i d_k} \leftarrow findMetric(m_i, d_k)$
  $cost \leftarrow \frac{M_{(m_i, d_k)}}{Sum}$
  if $cost >= threshold$ **then**
    $Prob\_temp \leftarrow Prob\_temp + cost$
    $Selected\_DAP \leftarrow d_k$
  end
end
return $Selected\_DAP$

Algorithm 1: DAP selection algorithm

V. Performance Evaluation

A. Simulation Environment

B. Simulation Results

Na figura 1 foi escolhido um n localizado geograficamente com a mesma proximidade entre 2 DAP e no meio da rede —-**explicar a semente**. Esta escolha adequada para entendermos como o comportamento da proposta na escolha dos DAP e o seu impacto no desempenho. Como visto, a escolha do **alfa** afeta o comportamento na escolha de DAP e notamos como o limiar mais baixo faz com que seja escolhido o DAP mais afastado e no somente os 2 mais prximos. O limiar mais alto faz com que a proposta faa escolhas alternando entre os 2 DAP mais prximos com melhores mtricas excluindo o terceiro DAP por possuir mtrica pior. A referłncia (multi-dap) j no faz trocas entre os DAP, somente ao final escolhido o DAP 2 por ter superado a mtrica do DAP 1. Aps a ocorrłcia da falha no tempo 300s verifica-se que este comportamento ir determinar como ser o comportamento futuro aps a ocorrłncia da falha do DAP 2 (fig 2). Notamos que a proposta com limiar de 30% (fig 2(a)) o n 16 sempre entrega pacotes para um dos DAP. A proposta com limiar de 85% (fig 2(b)) o comportamento foi diferente chegando a ficar 64 seg sem entregar um pacote para um dos DAP aps a falha. A referłncia (fig 2(c)) notamos um comportamento mais sensvel em relao falha chegando a ficar 81 seg sem entregar um pacote para um dos DAP.

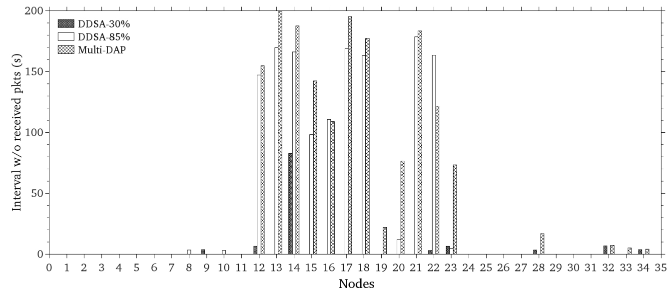


Fig. 3. Sum of intervals without receiving packets in any DAP

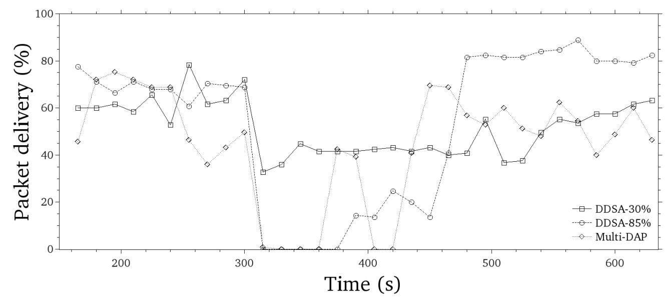
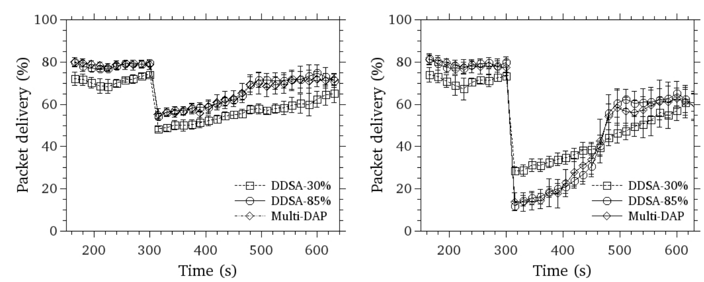


Fig. 4. Packet delivery of node 16 using 15 seconds interval — **usar s uma semente**

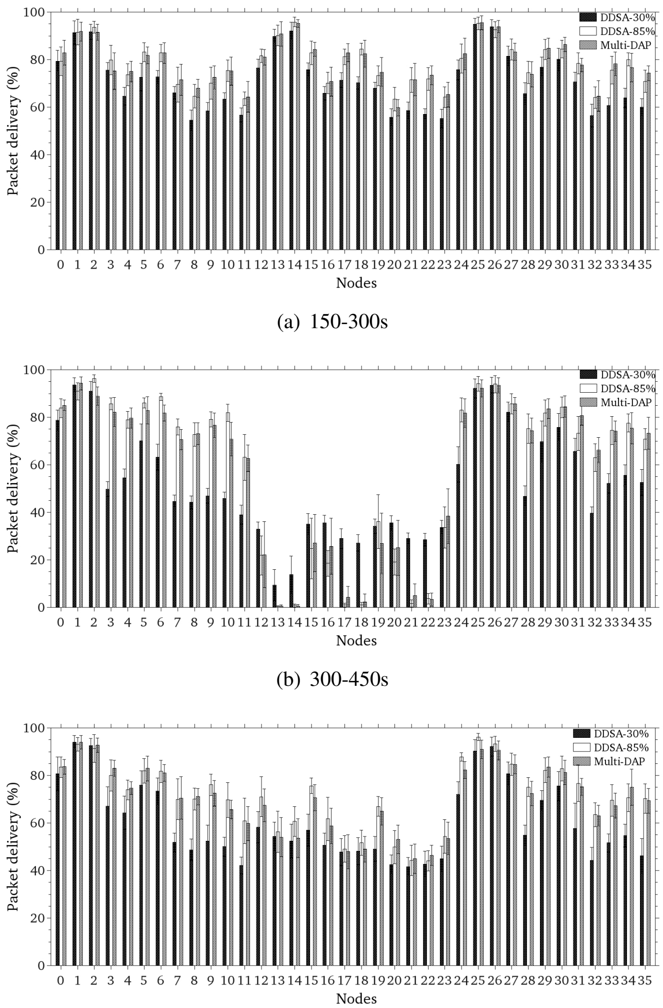


(a) all nodes (b) central nodes (12 to 23)

Fig. 5. Packet delivery using 15 seconds interval

Para verificarmos este comportamento para outros ns foi somado todos os intervalos em que no houve recebimento de pacotes em qualquer um dos DAP (fig 3). Percemos que este comportamento se repete para os ns da regio central da rede (ns 12 ao 23). COLOCAR A MDIA E EXPLICAR. No n 14 a proposta com limiar de 30% somou 82 seg sem enviar pacotes, mas que ficou muito abaixo dos 166 seg da proposta com 85% e da referencia com 187 seg. no total. Este n e o n 13 so os mais prximos do DAP falho sofrendo mais influłncia desta falha. mdia do multi 104,78 s, 85 106,86 30 14,57358

Na figura 4 analisado o comportamento de entrega de pacotes do n 16 durante a falha em intervalos de 15 seg. Nota-se que no DDSA-30% a queda na taxa no foi to acentuada quanto nos outros ficando cerca de 48% melhor que o DDSA-85% e o Multi-DAP. Isto evidencia que a tendłncia de distribuir mais pacotes do DDSA-30% entre os DAP o torna mais robusto que os outros quando ocorre uma falha de DAP.



(a) 150-300s

(b) 300-450s

(c) 450-650s

Fig. 6. Packet delivery in three periods: 150-300, 300-450 and 450-650. **estes grficos comparam por periodo e no por proposta**

Colocar que em todas as sementes O comportamento de todos os ns apresentado na figura 5(a) notamos que o DDSA-30% tem um desempenho um pouco menor que os outros. Isto se deve ao fato dele fazer uso de DAP com mtricas no to boas e que esto distantes do n de origem. Esta escolha reflete na sua performance ficando um pouco pior em relao aos outros que utilizam DAP com mtricas melhores e mais prximos ao n de origem. Em relao a regio central da rede, a mais afetada pela falha do DAP, a situao se inverte (fig. 5(b)) com o DDSA-30% melhor 16,5% que o DDSA-85% logo aps a falha e de at 17% em relao ao Multi-DAP. Aps o tempo 450 seg as curvas se cruzam demonstrando que a partir deste tempo a maioria dos ns tomam conhecimento da falha do DAP.

Por ltimo na figura 6 apresentado um histograma comparando cada etapa da simulao onde temos o perodo antes da falha de 150s at 300s, durante a falha de 300s at 450s e de recuperao da falha de 450s at 650s. observado que a regio central da rede a mais afetada pela falha do DAP. O DDSA-30% o menos afetado pela falha com resultados bem acima do DDSA-85% e o Multi-DAP com a maioria dos ns da regio central apresentando taxas muito baixas.

VI. Conclusion

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