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RESEARCH ARTICLE

Buffer Cluster Scheduling Scheme for Smart Grid Advanced Metering Applications

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ABSTRACT: - Energy consumption in outlook bright energy networks (or Smart Grids) will be based on grid-integrated near-real-time transportation between various grid elements in generation, transmission, distribution and loads. This paper discusses some of the challenges and opportunities of communications research in the areas of smart grid and smart metering. In particular, we focus on some of the key communications challenges for realizing interoperable and future proof smart grid/metering networks, smart grid security and privacy, and how some of the existing networking technologies can be applied to energy management. Finally, we also discuss Buffer cluster Scheduling scheme for Smart Grid Advanced Metering Applications.

keywords—Smart grid; smart metering; demand response; interoperability; standards; wireline and wireless communications; renewable energy; security; privacy

I.INTRODUCTION

Renewable energy sources offer a key solution to this problem; however, their integration into existing grids comes with a whole new set of barriers, such as the intermittency of generation, the high level of distribution of the sources and the lack of proven distributed control algorithms to manage such a highly distributed generation base. Historically, the electrical grid has been a *broadcast* grid (i.e. few-to-many distribution), where a few central power generators (i.e. power stations) provide all the electricity production in a country or region, and then ‘broadcast’ this electricity to the consumers via a large network of cables and transformers. Based on load forecasting models developed over time, the utility providers generally over-provision for the demand (considering peak load conditions). If the demand increases above the average, they may have to turn on the peaker plants1 which use non-renewable sources of energy (e.g. coal fired plants) to generate additional supply of energy to cope with the demand. The provisioning for peak load approach is wasteful when the average demand is much lower than the peak because electricity, once produced, has to be consumed as grid energy storage is expensive [2]. Secondly, setting up and maintaining the peaker plants are not only environmentally unfriendly but also expensive. Also, given the increasing demand for energy, it may be difficult, perhaps impossible in the longer run, to match the supply to this peak demand. What is attractive in such a situation then, is to match the demand to the available supply by using communication technology (two way communications between the grid and the customer premises) and providing incentives (e.g. through variable pricing) to the consumer to defer (reschedule) the load during times when the expected demand is lower so as to improve utilization of the available capacity. This necessitates the flow of metering information from the customer premises to the grid to identify the demand, and control information (e.g. pricing information) in the other direction to coerce the customer into adapting their demand. As mentioned earlier, since the legacy grid is a broadcast grid, this motivates the need for a communications infrastructure and protocols to support the aforementioned functionalities. While the legacy grid has served well for the last century or so, there is a growing need to update it, from the points of view of both the aging infrastructure and the new environmental and societal challenges. As a result, national governments and relevant stakeholders are making significant efforts in the development of future electrical grids or Smart Grids.

A smart grid is an intelligent electricity network that integrates the actions of all users connected to it and makes use of advanced information, control, and communications technologies to save energy, reduce cost and increase reliability and transparency. Development of this new grid will require significant efforts in technology development, standards, policy and regulatory activities due to its inherent complexity. A proper demand management through the smart grid technology has the potential to yield significant savings in the generation and transmission of energy. This is mainly due to the reduction of number of peaker plants needed to cater for peak demand that occurs only a small percentage of time. For example, it has been reported in [3] that in Europe, five to eight percent of installed capacity is used only one percent of the time. By deferring the peak demand to off peak Times, the capacity and transmission cost could be reduced up to 67 billion euros in Europe [3]. An annual potential value generation up to 130 billion dollars by 2019 has been forecast by McKinsey in [4] for a fully deployed smart grid in the US. The work in [5] states that even a conservative estimate of potential saving due to grid modernization is 40 billion dollars per year. In addition to the direct savings, there are many important economical and societal benefits such as reduction of CO_2 emissions, integration of renewable energy, elimination of regional blackouts and reduced operational costs via for example automated meter readings.

II.RELATED WORK

One of the most important issues in smart grid (as Defined in the us energy independence and security act Of 2007 [1]) is to provide a reliable and secure two-way end to End communications system for the advanced metering Infrastructure (ami). The aim system aims at providing Consumers with knowledge of their energy usage and the Capability of monitoring and controlling the electrical system Components. While networking technologies and systems have Been greatly enhanced, the smart grid faces challenges in Terms of reliability and security in both wired and wireless Communication environments. For instance, smart home appliances represent a major part of the smart grid vision of improving energy efficiency and they have to communicate with entities and players in other smart grid domains via Home area networks and neighborhood area networks. For Inter-operable networks, the appropriate use of wired and Wireless technologies has been the main focus for smart grid Last mile communication networks. One example of the latter power line communication (plc) [2], which is receiving Considerable attention for home area networking applications. At the same time, wireless lan (wlan) techniques, such As the ieee 802.11 family of standards [3] with their maturity And cost effectiveness, have been extensively deployed for Wireless access and home entertainment. However, to provide A large coverage area for aim in residential areas, multi-hop Communication is vastly favored over long-range single-hop Links. Indeed, the benefit of multi-hop transmissions is that Of combating the rapid decay of the received electromagnetic Signal strength, as the communication distance increases. Although there has been a tremendous advancement in mesh networking, from the architectural point of view, the ami Network should be designed to ensure a high degree of Reliability, self-configuration, and self-healing. Meeting these Requirements depends not only on the selection of a mesh Routing protocol, medium access control (mac) protocols, And physical (phy) layer, but also on the nature of the traffic At its application layer. For example, the time- varying traffic generated under emergency Situations poses a significant challenge in ensuring The reliability and timeliness of the smart grid network.

In Particular, outage management is one example where a system expects to receive power outage notifications and an exchange of information among all the meters. This situation tends to Increase traffic load, resulting in severe network congestions. Furthermore, in a multi-hop mesh network, a meter which represents a mesh node, should not only transmit its own Generated packets, but also those received from neighboring Meters. In the case of a conventional neighborhood area network, a Residential area is normally divided into separate regions where Meters (i.e., mesh nodes) in each region communicate with the Ami head end through their local gateway point. Under such Conditions, meters closer to the local gateway (i.e., last hope Nodes) are expected to experience more severe congestion Than those further away and this could create a bottleneck, Especially under outage conditions. In order to allow collective Participation in the routing, it is advantageous to combine all The sub-networks into a larger network with multiple gateways Where meters can access to any of the gateways based on local Traffic activity [4]. Multiple gateway networks, also known as any-cast Services, Have been an important issue for internet access. Their Function is to provide a mechanism that can select one of Many servers in the network [5], [6]. For mobile ad-hoc and Sensor networks, any-cast communications can be applied in Situations where there are multiple sinks in the network and the main strategy is to find the nearest sink [7]–[9].with these Networks another challenge arises from the shared medium if a Mac/csma (carrier sensor multiple access) protocol, such As ieee 802.11, is used. In this situation, interference due to Traffic flows sharing the same path as well as other traffic using Different links, could affect the network throughput and delay Performance. Recently, there has been increasing interest in the design of distributed csma algorithms at the mac layer to maximize network performance [10]–[15]. In [12] a csma Algorithm with a rate control has been proposed for multi-hop Networks. The combined algorithm can achieve an optimal Performance under ideal conditions. The authors in [12] have also expanded their analysis for any-cast and multi-cast services, which are presented in the appendix in [13]. However, the analysis which is based on the assumption of continuous Back-off time and instantaneous channel feedback ignores the Effect of collusion. Although csma-based algorithms have Shown a throughput optimality, their delay performance for Practical applications can be worse than that of the max- Weight algorithm [10], [11], [15], [16]. The basic concept Of the max-weight (also known as back-pressure) algorithm For a multi-hop network was first introduced in [17].

It will Schedule any packet through a specific route according to the Queue-length difference of each single-direction single hop Link. Essentially, the scheduling algorithm presented in [17] Endeavors to mitigate the queue length difference between any Pair of mesh nodes in the network to the maximum extent. They provide a statistical analysis to prove that the algorithm is able to achieve the maximum stability region, albeit without providing any distributed solution. Since then, this algorithm has found its application in many areas of wired or wireless Communication systems [18]–[24]. Additionally, a large number of variants of the algorithm were put forward with different Objective functions (of) in wireless multi-hop networks. For instance, in [25], the authors modify the of so that Head-of-the-line packet delays are taken into consideration. In [26], [27], a related delay-based index policy that provides Exponential weight to the delay (the so-called exponential Rule) is shown to be throughput-optimal. The authors of [28] consider a single transmitter connecting to a number of destinations Via an ad-hoc network. A separate queue is maintained for each destination at each relay node.

However, the delay Performance of the original back-pressure algorithm [17] may become uncontrollable for the following two reasons. Firstly, given f classes of flows in the entire ad-hoc network, which are distinguished by the destination, f queues remain at each Mesh node, although only one queue is served at a time. Based On this structure, the complexity of maintaining the queuing Data at each node increases proportionally with the number of

Potential destinations, which further increases the delay of the Original back pressure algorithm. Secondly, due to a lack of Contribution from the hop-count to the of, it is quite possible that the original back-pressure algorithm in [17] may route some packets through a much longer route rather than the Shortest path to the obliged destination. Against this background, the main objective in this paper is to design a low complexity max-weight distributed routing Algorithm that can achieve a low delay performance. Therefore, our first contribution is to propose a hop-count based Single-class back-pressure scheduling algorithm, which can significantly reduce the delay when compared with the Original back pressure algorithm [17]. For instance, the Authors of [29] have put forward a novel of for the centralized Algorithm, which jointly takes into account the hop-count as Well as the queuing data waiting in the buffer for each Node's concern. However, each packet has a single destination, which doesn't change the multi-class queuing data structure Maintained at each node where a separate queue is maintained for every class of packets. Since the destination of each new Packet injected into the mesh network was determined and could be any of the nodes constituting the network, the hop Counts to all potential destinations need to be obtained from Time to time. This definitely adds to the traffic load, as well As the complexity of calculating of, hence increasing the Delay of the proposed algorithm. As opposed to previous works [17], [25]–[29] our second Contribution is to embed our proposed scheduling Algorithm into a multi-gate dynamic network structure, where the Destination of any packet injected is not fixed beforehand. In other words, the final destination may vary as the packet Passes through each relay-node and cannot be determined, until it reaches the final destination. Given this flexibility, the Processing delay is significantly reduced as only one queue needs to be maintained at each node. Based on the above distinct features of the proposed algorithm compared with the Original back-pressure algorithm [17], our next contribution is to quantify the stability region and analyze the reduction of the overall network delay, which is a result of employing Our scheduling algorithm. We will analyze the contradictory Impact of the key parameters employed by the of of our Algorithm to enhance the throughput and reduce the delay, Which leads to the necessity of finding appropriate values For the parameters, so that a tradeoff between enhancing The stability region and reducing the network delay can be Maintained. Additionally, we prove that the network is able to remain stable as long as the arrival rate vector lies inside the Stability region. The scheduling solutions presented by all the above mentioned Back-pressure based algorithms, i.e. [17], [29], are achieved by optimizing the centralized of is via exhaustively searching all possible scheduling solutions. These centralized Algorithms require too much time and complexity to implement in the context of ad-hoc wireless communication. Thus, a large variety of distributed algorithms, such as those of [30]–[36] were proposed to apply the featuring the Centralized algorithms. Our fourth contribution is to derive the distributed from the centralized of used by our Scheduling algorithm, so that it can be used for practical Implementation. Finally, for our implementation we use an extended experimental test-bed developed in [4]. This test bed Consists of four gateways and 48 mesh nodes where each Node is generating variable bit rate (vbr) traffic, which are then forwarded towards the master gateway as their final Destination.

III. METHOD OF SCHEDULING ALGORITHM

Buffer clustering schedule scheme to be applied, through which, the traffic will reflect a certain impact on the nodes taking into account the EC trade-offs. Wireless devices should consider the incoming traffic, in order to adapt and reflect a certain feedback to the EC mechanism. A Middleware which hosts traffic changes and has a direct impact through the estimated scheme presented in Section III.B is shown in Figure 1. Figure 1 shows a cross layer interaction through a mechanism for traffic wariness in an end-to-end manner. In particular, real-time media traffic such as voice and video typically have high data rate requirements and stringent delay constraints, whereas wireless nodes generally have limited or momentarily connectivity. The proposed middleware enables the data packets to be traversed and manipulated through the utilized Data Link, Network, and Transport layers by considering the traffic awareness mechanism and the model for volume estimation to be reflected on these layers. The proposed traffic-aware mechanism evaluates (after the bootstrap process of the system) the estimated (quantified as Volume/Capacity) traffic that is destined for each node. In this way it enables –through the proposed mechanism- estimation for the next slot sleep duration of the node. This evaluation is performed in an interactive way through the mechanism in Section III.B.

These mechanisms are performed in order to tune the wireless interface of each device to sleep/wake according to the activity of each individual device in the resource exchanging path. Packet classification methodology was utilized as in [15] in order to mark the packets that are exchanged whether they are delay sensitive or not. In turn, if packets are considered as delay sensitive, strict deadlines are applied by the sender, according to the specifications set in the network. In the case where packet deadlines cannot be satisfied, then cached packets of nearby nodes, enable recovery using the promiscuous caching [18]. This mechanism enables the resources' replication and increases the resource sharing reliability [18]. The quantitative mechanisms shown in Figure 1, are depicted in the following sections with the quantitative analysis. Generic combined with clustering s are efficient search methods based on principles of natural selection and population genetics. They use randomized operators operating on a population of candidate solutions to generate a new population of candidates in the search space (Goldberg [8]). For any GA, a chromosome representation is needed to describe each individual in the population of interest. Each individual or chromosome is made up of a sequence of genes from a certain alphabet. Though the alphabet was limited to binary digits in Holland's original design [13], other very useful problem-specific representations of an individual or Chromosome for function optimization has also been proposed. GAs can search the solution space for optimal solutions very efficiently by using evaluation and genetic operator functions to maintain the useful schema in the population. For example, in a chromosome with a binary string representation of length eight, the string 101#####, where the # represents a "wild card", either 0 or 1, is a schema. Other types of schema are possible also. Individuals exhibiting a schema which results in higher fitness will have a higher probability of survival by the selection process in each generation and thereby will have a higher probability of being selected for mating and generating offspring which are likely to exhibit the same schema. (Mating is accomplished by the crossover operator function, in which the pair of mating chromosomes exchanges substrings to produce a pair of offspring.) The new offspring usually include improved solutions since they tend to inherent the good schema, i.e., the good schema persist in the population over multiple generations. This has been discussed in detail by Michalewicz [18]. This section provides only a brief introduction of GAs; interested readers are referred to the excellent book by Goldberg.

IV.EXPERIMENT RESULT

We start our analysis by first looking at the scenario with fixed number of UEs per sector and full-buffer traffic model. Only one CC is configured with 10 MHz bandwidth in this scenario. Fig. 3 shows the average throughput gain versus different number of UEs per sector. The reference scenario is single cluster scheduling without MU-MIMO. The gain of dual-cluster scheduling over single cluster scheduling increases as the number of UEs increases until reaching the maximum value at certain point, i.e., 6 UEs per sector in our case. Then the dual-cluster scheduling gain gradually decreases as the number of UEs increases. That is because when the number of UEs per sector is low; with dual-cluster scheduling UEs have more chance to exploit frequency diversity than single cluster. But when the number of UEs per sector is high, the gain brought by dual-cluster scheduling is decreasing due to multiuser diversity gain. MU-MIMO gain increases monotonically as the number of UEs increases due to the reason that higher number of UEs will bring higher multi-user diversity. When MU-MIMO is combined with dual-cluster scheduling, the average throughput gain can be up to 56% with 10 UEs per sector compared with single cluster scheduling without MUMIMO. It is much higher than the sum of gains brought by dual-cluster scheduling alone and MU-MIMO alone because dual-cluster scheduling allows to fully exploiting the gain of MU-MIMO. Therefore it is recommended that dual-cluster scheduling is used in combination with MU-MIMO. Next we evaluate the performance of multi-cluster scheduling with MU-MIMO and CA in bursty traffic model. Two CCs, each with 20 MHz bandwidth, are configured. Fig. 4 shows the cell edge user throughput versus the offered load in different scenarios. It is shown that the coverage of LTEA UEs is almost the same as that of Rel'8 UEs. In other words, there is no gain in coverage by applying multi-cluster scheduling or CA in uplink. That is because at the cell edge, UEs usually experience high path loss and are limited by the maximum transmission power. In fact, with LAPC deployed, cell edge UEs are configured to transmit with maximum power. Even if those cell edge LTE-A UEs are assigned to multiple clusters and CCs, they do not have sufficient power to exploits the increased transmission bandwidth, and may even result in a performance loss due to the effect of MPR. Therefore, cell edge LTE-A UEs are assigned on only one cluster and one CC, which results in almost the same coverage performance compared with Rel'8 UEs. Fig. 5 shows the average user throughput versus the offered load in different scenarios.

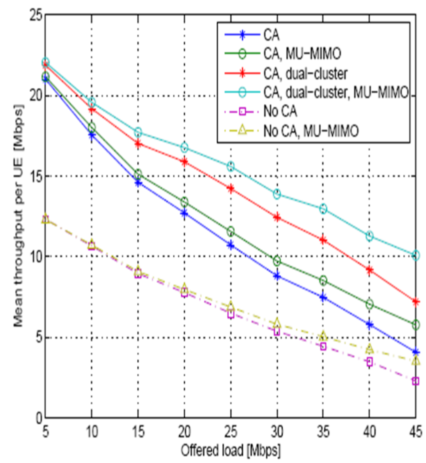

Fig.1. Average user throughput under different traffic loads in different Scenarios,2*20 MHz with finite-buffer bursty traffic model

With CA and multi-cluster scheduling, the average user throughput of LTE-A UEs is significantly higher than that of Rel'8 UEs. In our proposed CC selection algorithm, we distinguish between power-limited and non-power-limited LTE-A UEs based on users' path loss. Power-limited LTE-A UEs are assigned on only one CC and single cluster so that they will not experience any loss from being scheduled over multiple CCs and clusters, while LTEA UEs not operating close to their maximum transmission power are assigned on multiple CCs and dual clusters so that they can benefit from the advantages of CA (i.e., increased transmission bandwidth) and multi-cluster scheduling

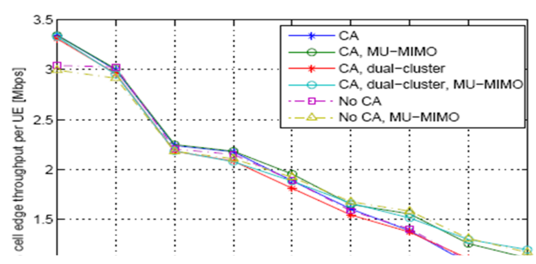

Fig.2.Cell edge user throughput under different traffic loads in different scenarios, 2*20 MHz with finite-buffer bursty traffic model

Offered load [Mbps]

Fig.2. Cell edge user throughput under different traffic loads in different Scenarios,2*20 MHz with finite-buffer bursty traffic model

V. CONCLUSION

In this paper we have presented an overview of the unique challenges and opportunities posed by smart grid communications, e.g. interoperability, new infrastructure requirements, scalability, demand response, security and privacy. The success of future smart grid depends heavily on the communication infrastructure, devices, and enabling services and software. Results from much existing communications research can be potentially applied to the extremely large-scale and complex smart grid, which will become a killer application. In parallel to technical issues of smart grids, we have also discussed the current status of standardization on smart metering in Europe. It is very desirable to have a single set of standards defining the interfaces, communications and data exchange formats for smart metering and smart grids in Europe due to the current pressure on deploying smart metering solutions.

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