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Measuring the Gap: a statistical approach for online evaluation and forecasting of human participation in Demand Response programmes

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Intelligent Neighbourhood Energy Allocation & Supervision IDEAS

DR-BOB

REACT

SUSTAINABLE PLACES 2022

Sep. 6 - Sep. 9, 2022 | Nice, France

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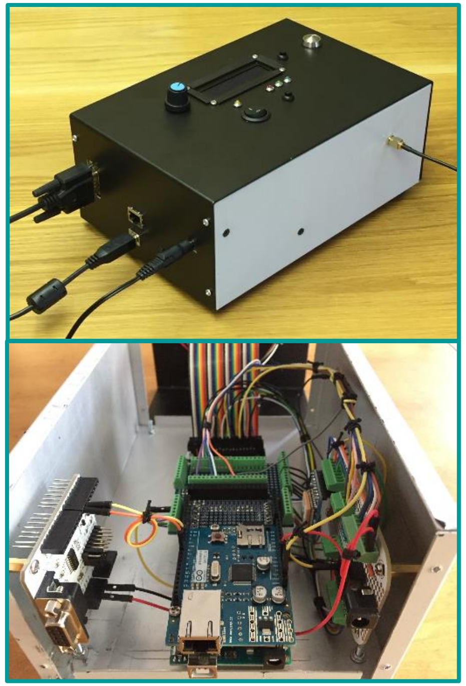
Overview for today:

A well-known gap exists between perceptions of how effective DR should be and the practical reality as observed in field trials and demonstrations. For a wider roll-out of DR, which unknown/varying participation and an uncertainty gap in assumptions: how can a system operator or aggregator effectively measure and forecast residential DR participation in a meaningful way, when planning or optimizing an economic dispatch?



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Intelligent Neighbourhood Energy Allocation & Supervision
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Changes for the Better

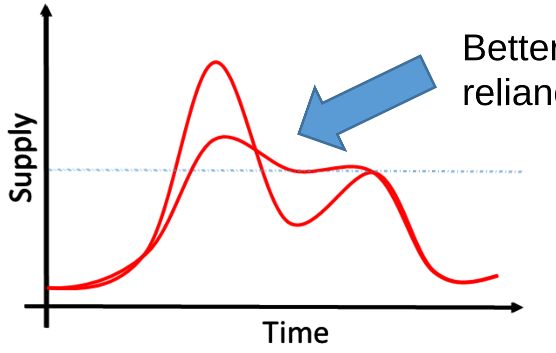
DR-BOB

REACT
Renewable Energy for Self-Sustainable Island Communities

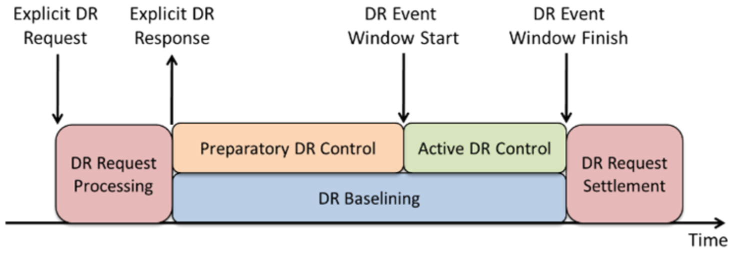
TEF Silver Teaching Excellence Framework

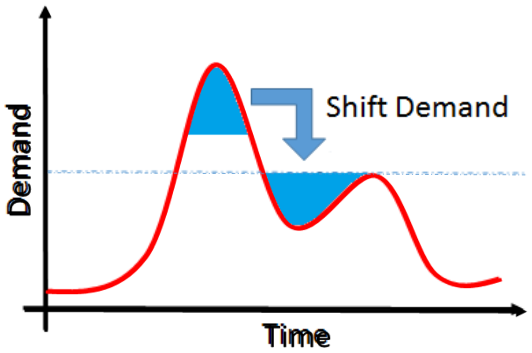
INVESTORS IN PEOPLE Gold Until 2021

Demand Response (Commercial)

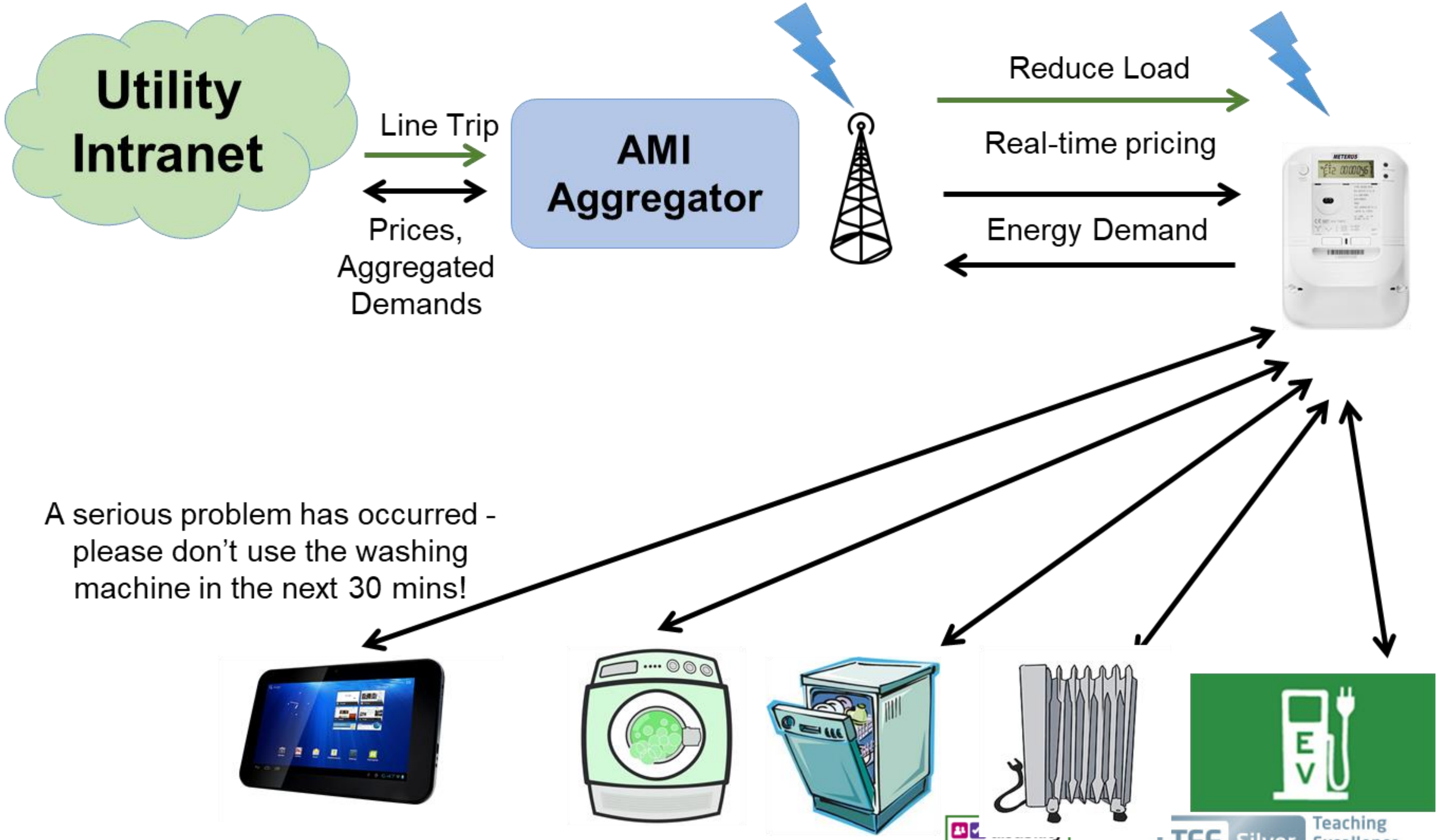


Better use of renewables + less reliance on expensive peaking units



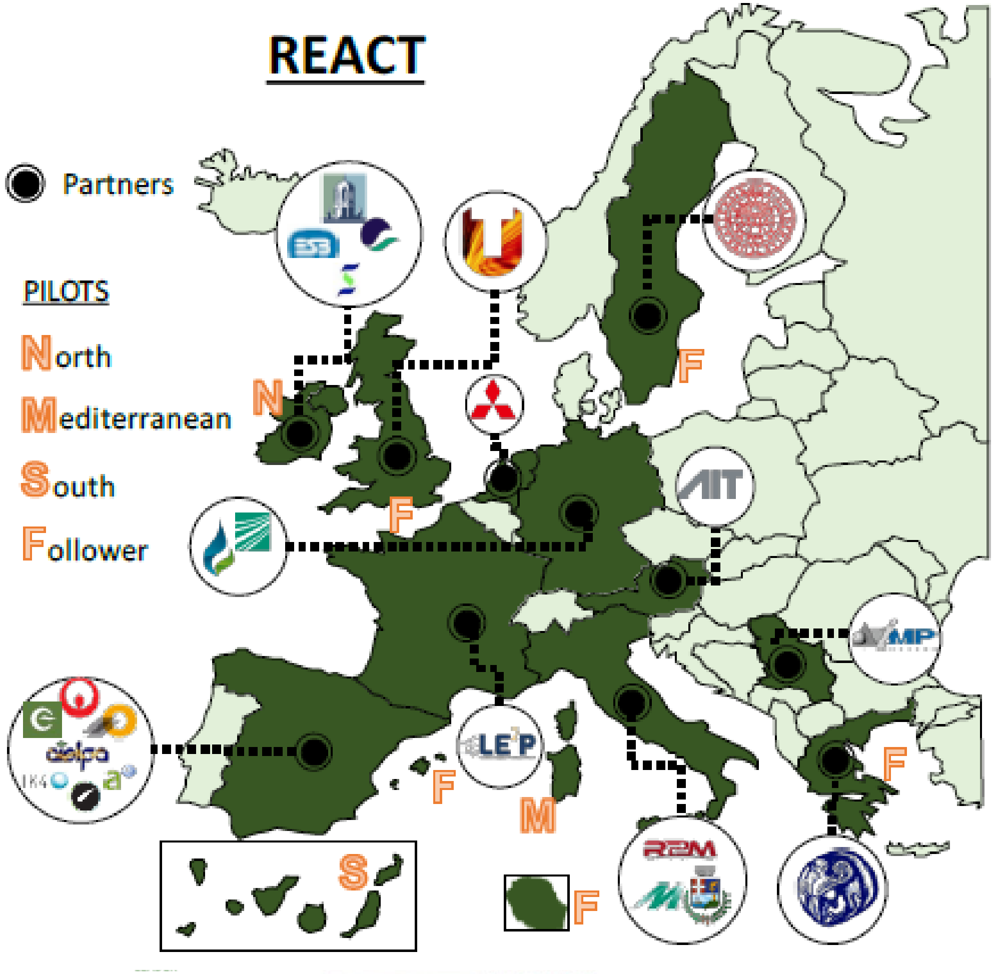


Demand Response (Residential)



Renewable Energy for self-sustAinable island CommuniTies

- H2020 funded project, Jan 2019 - Dec 2023
- LC-SC3-ES-4-2018-2020 (Decarbonising energy systems of geographical Islands)
- 10 million budget, 23 partners from industry, energy authorities, universities and research institutes



Demand Response

- ‘Demand response (DR) provides an opportunity for consumers to play a significant role in the operation of the electric grid by reducing or shifting their electricity usage during peak periods in response to time-based tariffs or other forms of financial incentives’

- ‘The analysis presented identifies how expectations about building occupants and their behaviours are built into the DR scenarios (to be tested during the project demonstrations). **Initial findings suggest that building occupants’ energy use practices and routines may be different from those expectations**.’

- Recommendations in scenarios with active occupant responses include: prepare the engagement properly, use peer-to-peer approaches, training, coaching trajectories, engagement of occupants in identifying the ‘right’ message, format and timing to motivate their active participation, **considering that occupants themselves are best able to tell what works for them and what does not**.

ENERGY & ENVIRONMENT

Article

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SAGE

Mind the gap when implementing technologies intended to reduce or shift energy consumption in blocks-of-buildings

Sylvia Breukers[1], Tracey Crosbie[2] and Luc van Summeren[3]

Abstract

If the designers of technologies intended to reduce or shift energy consumption are not sensitive to how people live and work in buildings, a gap occurs between the expected and actual performance of those technologies. This paper explores this problem using the concepts of ‘design logic’ (designers’ ideas, values, intentions and user representations) and the ‘user logic’ (related in this case to how building occupants currently live and work in a building). The research presented unpacks the ‘design logic’ embedded in DR approaches planned for implementation at four blocks of buildings in a Horizon 2020 funded project, called “Demand Response in Blocks of Buildings” (DR-BoB). It discusses how the ‘user logic’ may differ from the ‘design logic’ and the potential impact of this on the performance of the technologies being implemented to reduce or shift energy consumption. The data analysed includes technical working documents describing the implementation scenarios of DR at four pilot sites, interviews and workshops conducted with the project team and building occupants during the first phases of the project. The analysis presented identifies how expectations about building occupants and their behaviours are built into the DR scenarios (to be tested during the project demonstrations). Initial findings suggest that building occupants’ energy use practices and routines may be different from those expectations. The paper illustrates how the concepts of ‘design logic’ and ‘user logic’ can be used to identify mismatches before technologies are implemented. The paper concludes with recommendations for improving the design and implementation of DR.

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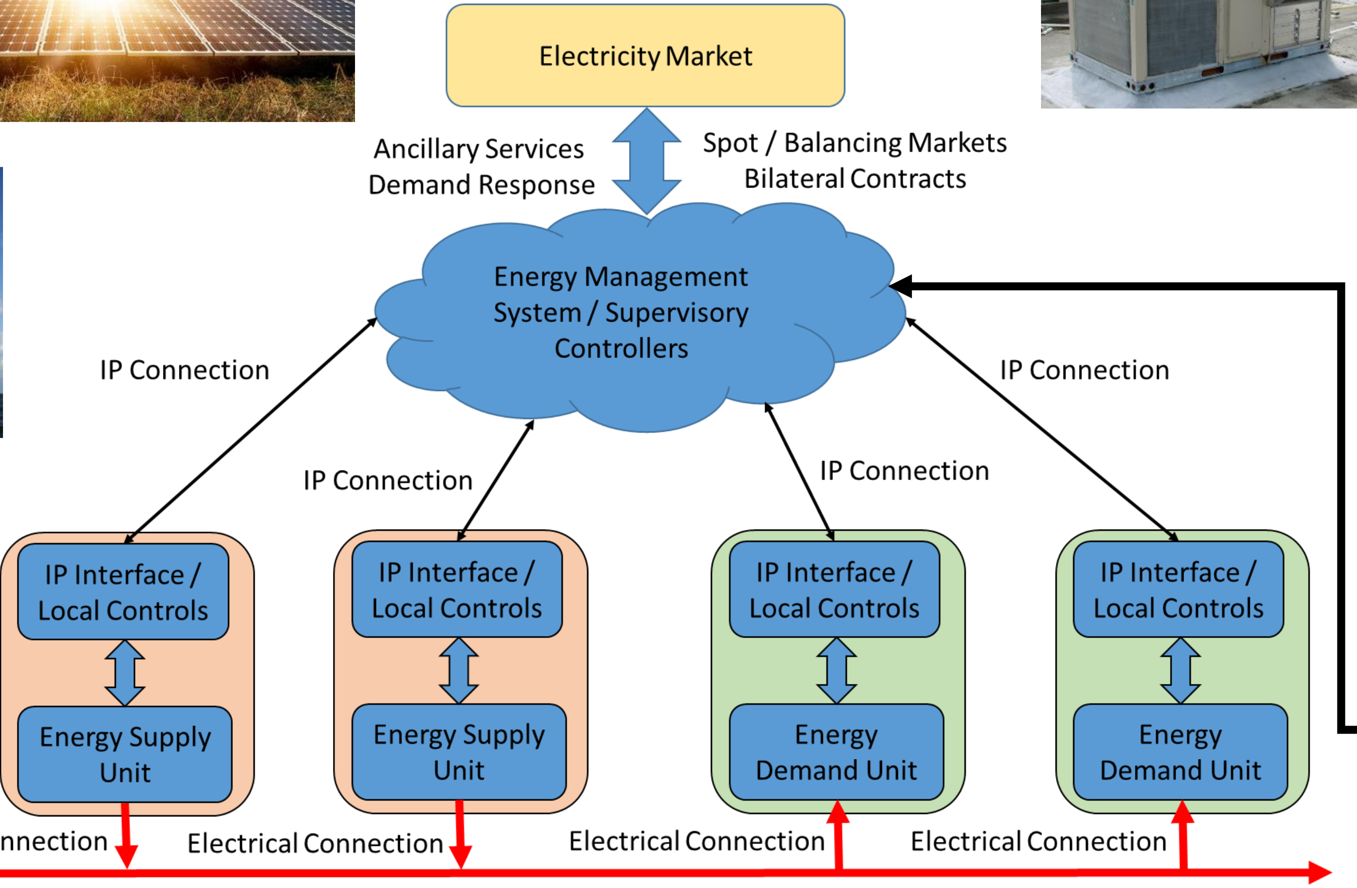
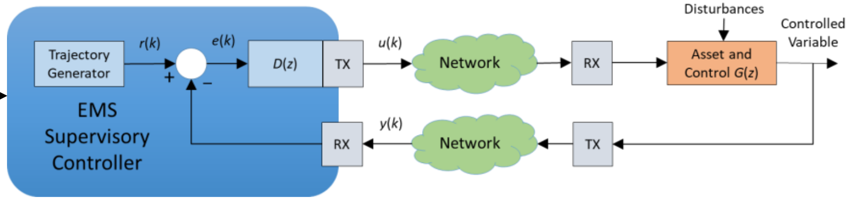
Smart Energy Management Systems 👍



$$D(z) = \frac{kpA(z)}{P(z) - kpB(z)}$$



Aggregated DR: How to model user response?

Minimize:

$$J(k)=\sum_{i=0}^{M}\left(T(k+i+d)-T_R(k+i+d)\right)^2+\lambda\sum_{i=0}^{M-1}\Delta u(k+i)^2$$

with respect to:

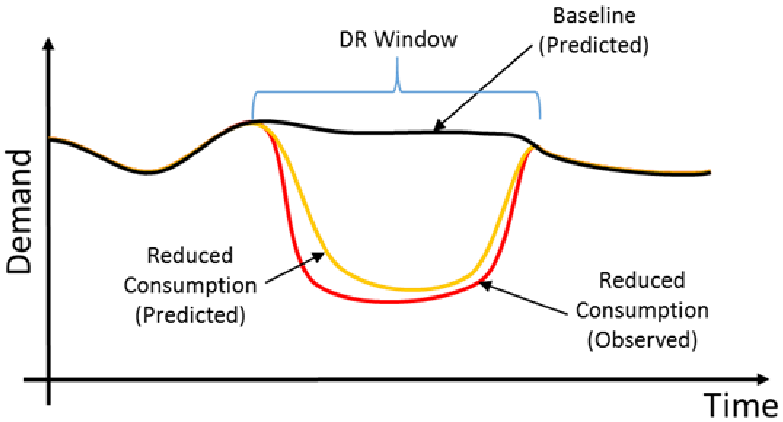
$$u(k+i),\quad 0\le i\le M-1;$$

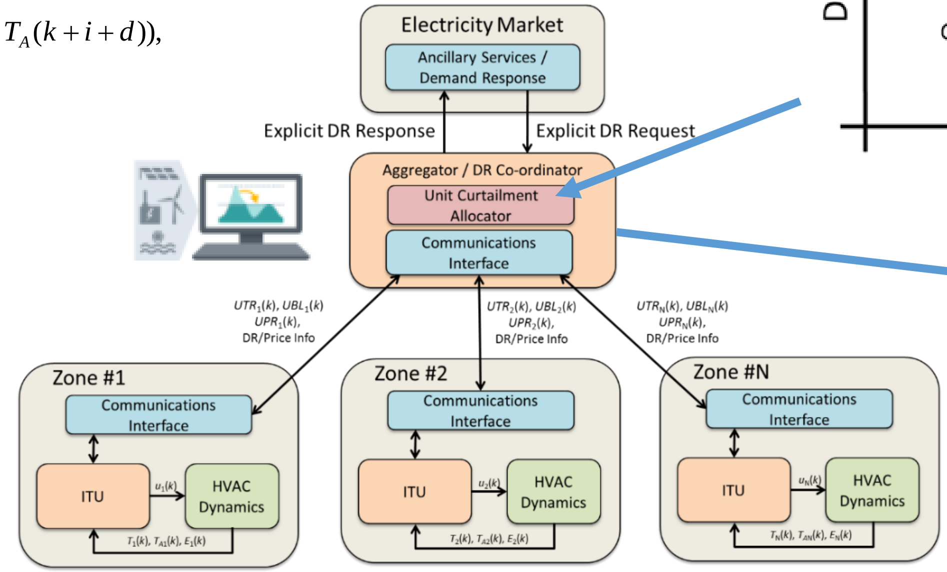
subject to:

$$T(k+i+d+1)=a\cdot T(k+i+d)+(1-a)\cdot\left(u(k+i)\cdot K_T+T_A(k+i+d)\right),$$
$$0\le i\le M-1;$$

$$u(k+i)\in\{0,1\},\quad 0\le i\le M-1;$$

$$U_L\le\sum_{i=0}^{M-1}\left(u(k+i)\cdot w(k+i)\right)\le U_U$$





User Behaviour Models ⇔ Statistics

Adaptive framework for DR user response

‘The ‘design logic’ should contain an understanding of the ‘user logic’ and in doing so consider the values, preferences, intentions, and use practices of the expected users of a given technology in its specific context.’

The realised design logic must forecast responses within confidence intervals

User Behaviour Models ⬄ Statistics

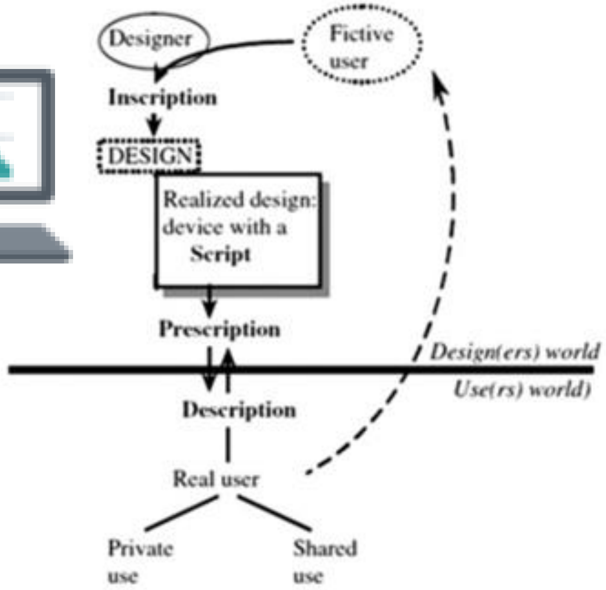


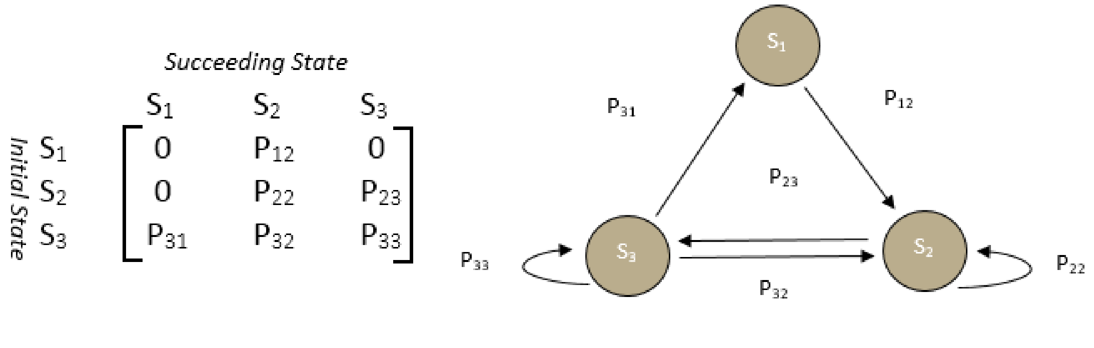
Figure 1. World of designers and users connected via script terminology[14] (p.224).

Measure responses against assumptions & refine the design

User Behavioral Models

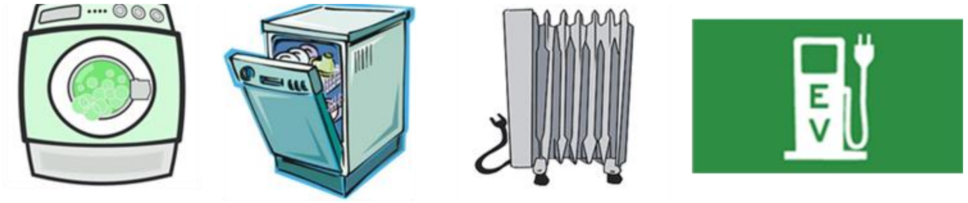
Discrete Markov Chains: probability of user (or load) moving between specific states of responding to specific events is stochastic:

Steady-state of Markov chain is a multinomial choice.



Transition Matrix **Transition Diagram**

For appliance curtailment after DR event, load reduction can be modelled as Boolean indicator variable for each appliance/load:



Static models: Probability of curtailment during DR event = p_1 p_2 p_3 p_4

Previous Work on Statistics

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Hindawi

Research Article

Improved Inequalities for the Poisson and Binomial Distribution and Upper Tail Quantile Functions

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The exact evaluation of the Poisson and Binomial cumulative distribution and inverse (quantile) functions may be too challenging or unnecessary for some applications, and simpler solutions (typically obtained by applying Normal approximations or exponential inequalities) may be desired in some situations. Although Normal distribution approximations are easy to apply and potentially very accurate, error signs are typically unknown; error signs are typically known for exponential inequalities at the expense of some pessimism. In this paper, recent work describing universal inequalities relating the Normal and Binomial distribution functions is extended to cover the Poisson distribution function; new quantile function inequalities are then obtained for both distributions. Exponential bounds—which improve upon the Chernoff-Hoeffding inequalities by a factor of at least two—are also obtained for both distributions.

1. Introduction

The Poisson and Binomial distributions are a good approximation for many random phenomena in areas such as telecommunications and reliability engineering, as well as the biological and managerial sciences [1, 2]. Let $Y \sim \mathrm{Poi}(m)$ be a Poisson distributed random variable having mean $m > 0$, and let $P\{Y \le k\}$ represent the cumulative distribution function (CDF) of Y with nonnegative integer support $k \in \{0, 1, \dots, \infty\}$:

$$P\{Y \le k\} = e^{-m} \sum_{i=0}^{k} \frac{m^i}{i!}. \quad (1)$$

Similarly, let $X \sim \mathrm{Bin}(n, p)$ be a Binomially distributed random variable with parameters $n \in \{1, 2, 3, 4, \dots\}$ and $p \in (0, 1)$, and let $P\{X \le k\}$ represent the CDF of X for integer support $k \in \{0, 1, \dots, n\}$:

$$P\{X \le k\} = \sum_{i=0}^{k} \binom{n}{i} p^i (1-p)^{n-i}. \quad (2)$$

Also, let the Rth quantiles of Y and X for $R \in (0, 1)$ be obtained from the functions $Q_P(m, R)$ and $Q_B(n, p, R)$:

$$Q_P(m, R) = \{\min k \in N : P\{Y \le k\} \ge R\}, \quad (3)$$

$$Q_B(n, p, R) = \{\min k \in N : P\{X \le k\} \ge R\}. \quad (4)$$

Due to numerical and complexity issues, evaluation of the exponential and Binomial summations in (1) and (2) through recursive operations is only practical for small values of the input parameters (m or np and k). Instead, a better solution is to evaluate the CDFs directly through either their incomplete Beta/Gamma function representations which can be approximated to high precision by continued fractions or asymptotic expansions [3]. With respect to the quantiles of the distributions given by (3) and (4), no methods to exactly evaluate these functions without iterating the exponential/Binomial sums—or alternately employing a search until the required conditions are satisfied—seem to be known. Typically, a binary search to determine the smallest k satisfying (3) or (4) evaluating the respective CDF at each step would be a better general solution, given some initial upper bound for

2013 25th Euromicro Conference on Real-Time Systems

Towards efficient probabilistic scheduling guarantees for real-time systems subject to random errors and random bursts of errors

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Abstract—**Real-time computing and communication systems are often required to operate with prespecified levels of reliability in harsh environments, which may lead to the exposure of the system to random errors and random bursts of errors. The classical fault-tolerant schedulability analysis in such cases assumes a pseudo-periodic arrival of errors, and does not effectively capture any underlying randomness or burst characteristics. More modern approaches employ much richer stochastic error models to capture these behaviors, but this is at the expense of greatly increased complexity. In this paper, we develop a quantile-based approach to probabilistic schedulability analysis in a bid to improve efficiency whilst still retaining a rich stochastic error model capturing random errors and random bursts of errors. Our principal contribution is the derivation of a simple closed-form expression that tightly bounds the number of errors that a system must be able to tolerate at any time subsequent to its critical instant in order to achieve a specified level of reliability. We apply this technique to develop an efficient 'one-shot' schedulability analysis for a simple fault-tolerant EDF scheduler. The paper concludes that the proposed method is capable of giving efficient probabilistic scheduling guarantees, and may easily be coupled with more representative higher-level job failure models, giving rise to efficient analysis procedures for safety-critical fault-tolerant real-time systems.**

Keywords- Probalistic Schedulability Analysis; Error models; Fault-Tolerance.

I. Introduction And Motivation

Real-time computing and communication systems are often required to operate with a pre-specified level of reliability in harsh environments. In many cases they may be subject to environmental hazards such as electromagnetic interference (EMI) and other forms of radiation, and also to excessive mechanical/electrical stresses. Exposure to hazards such as this can induce random errors into a system, which – if left uncorrected – may result in system failures [1][2]. In this paper we are principally concerned with schedulability analysis of real-time CPU tasks and messages which are or other EMI fault, leading to an erroneous state and the abortion of an executing job by a CPU or a transmitting message frame in a network. For crucial systems, the use of fault-tolerance (mainly in the form of temporal redundancy) is required such that the aborted job or message can be re-executed or re-transmitted [3][4]. Such a form of redundancy requires some temporal 'slack capacity' in the schedule; how much slack is required to be allocated depends upon many factors including the level of criticality in the service the system provides, the task/message parameters and scheduling algorithms and the nature of the error detection and correction mechanisms employed by the system. If insufficient slack is employed by a system to tolerate the effects of the errors it experiences, then aborted jobs or message frames will not be processed or delivered correctly before their deadlines and system failures may occur. Clearly then, a major factor that needs to be considered in the design of fault-tolerant real-time systems is the frequency and severity of the transient errors the system is likely to experience. In addition to sporadic error arrivals which are purely random and uncorrelated in nature, research has shown that errors are very likely to occur in short transient bursts (see [5-9] and the references therein). Therefore a representative error model must have the ability to include these types of bursty behavior within its domain of operation.

Although some approaches to fault-tolerant schedulability analysis employ models which capture these behaviors, to date this has been at the expense of greatly increased analysis complexity. In this paper, we develop a quantile-based approach to probabilistic schedulability analysis in a bid to reduce complexity whilst still retaining a rich stochastic error model capturing random errors and random bursts of errors. Our principal contribution is the derivation of a simple closed-form expression that tightly bounds the number of errors that a system must be able to tolerate at any time subsequent to the Synchronous Arrival Sequence (SAS) of its tasks in order to achieve a specified level of reliability. At the core of the technique is the use of a Markov-Modulated Poisson Binomial (MMPB) process; the

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On binomial quantile and proportion bounds: With applications in engineering and informatics

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ABSTRACT
The Binomial distribution is often used as a good approximation for many phenomena in engineering, medical, financial, and other applications involving discrete randomness. In many situations, for the purposes of risk management it may be required to estimate and/or track the probability of occurrence of a particular type of discrete event from a data sample, and then use such an estimate to predict outcomes from a larger sample. In this article, very simple but very accurate formulae are derived to support such actions. Analytic formulae are presented to tightly bound upper and lower estimates of a Binomial proportion to given confidence levels, and to tightly bound upper and lower estimates of a Binomial Quantile. Application to risk management are shown through synthetic and real-world examples, and accompanying analysis. It is argued that the formulae are simple enough to be embedded directly in machine learning and related analytics applications, and can also be manipulated algebraically to help analyze random behaviors in algorithms. The article concludes that the presented expressions are also useful to support decisions in situations in which specialist software may not be available.

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KEYWORDS
Binomial distribution, proportion estimation, quantile estimation, concentration inequalities, machine learning, engineering, bioinformatics

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1. Introduction

Binomial Proportion Estimation

Extending the normal approximation and Wald-Laplace interval concepts, Michael Short has shown that inequalities on the approximation error between the binomial distribution and the normal distribution can be used to accurately bracket the estimate of the confidence interval around $\hat{p}$:[6]

$$\frac{k+C_{L1}}{n+z^2} - z\sqrt{\frac{nk-k^2+C_{L2}n-C_{L3}k+C_{L4}}{n(n+z^2)^2}} \le \hat{p} \le \frac{k+C_{U1}}{n+z^2} + z\sqrt{\frac{nk-k^2+C_{U2}n-C_{U3}k+C_{U4}}{n(n+z^2)^2}}$$

where $\hat{p}$ is again the (unknown) proportion of successes in a Bernoulli trial process, measured with n trials yielding k successes, z is the $1-\frac{\alpha}{2}$ quantile of a standard normal distribution (i.e., the probit) corresponding to the target error rate α, and the constants $C_{L1}, C_{L2}, C_{L3}, C_{L4}, C_{U1}, C_{U2}, C_{U3}$ and C_{U4} are simple algebraic functions of z.[6] For a fixed α (and hence z), the above inequalities give easily computed one- or two-sided intervals which bracket the exact binomial upper and lower confidence limits corresponding to the error rate α.

Binomial Quantile Estimation

Similarly for quantiles:

Lower:

$$Q_L(n, p, (1 - R)) \leq \left\lfloor np - C\sqrt{np(1-p)} - \frac{C^2}{3} - 1 \right\rfloor$$

$$C = \Phi^{-1}(R)^2$$

Upper:

$$Q_U(n, p, R) \leq \left\lceil np + C\sqrt{np(1-p)} + \frac{C^2}{3} \right\rceil$$

$$C = \Phi^{-1}(R)^2$$

Adaptive framework for DR user response

User Behaviour Models ⇔ Statistics

This leads to extremely simple algebraic expressions to track the confidence interval around an unknown proportion when information updates are revealed, and forecast a response (within an interval, e.g. 95% confidence)

$$Q_L(n, p, 0.05) \geq \left\lfloor np - 1.645\sqrt{np(1-p)} - 1.902 \right\rfloor$$

95% Safe Estimate

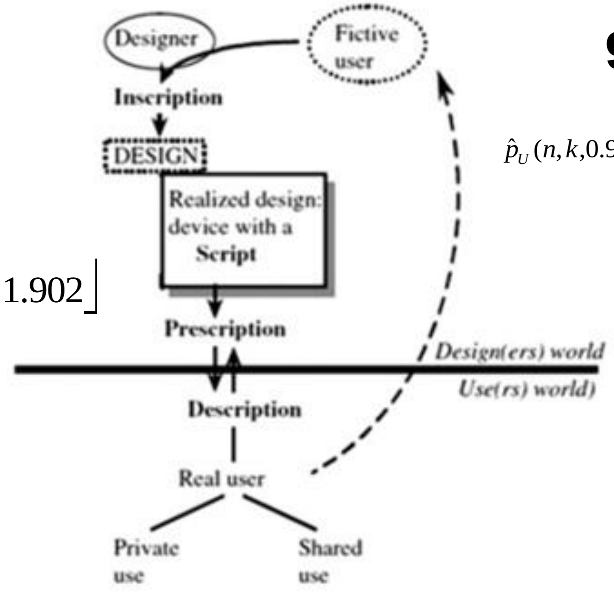


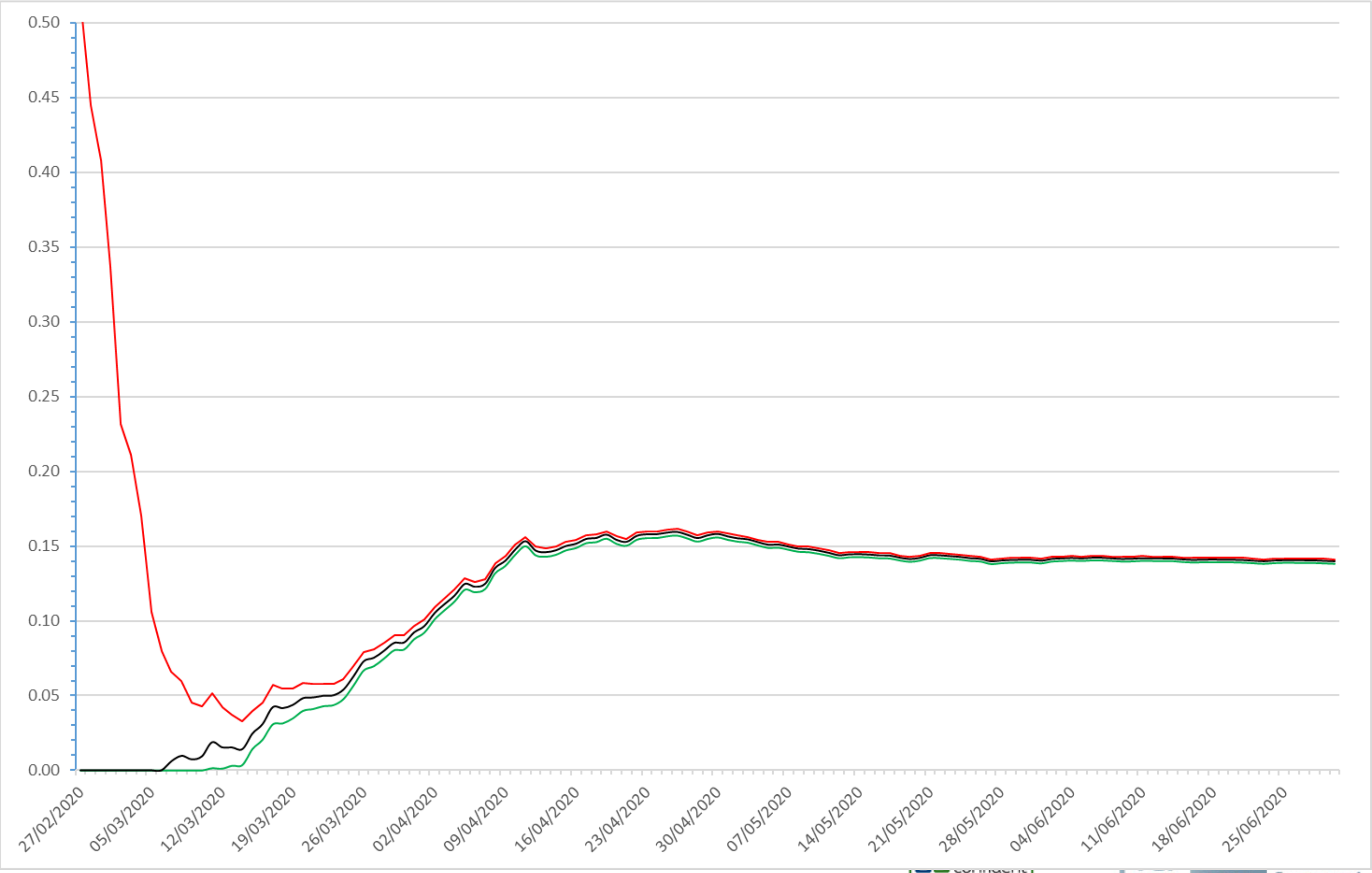
Figure 1. World of designers and users connected via script terminology[14] (p.224).

95% Safe Estimate

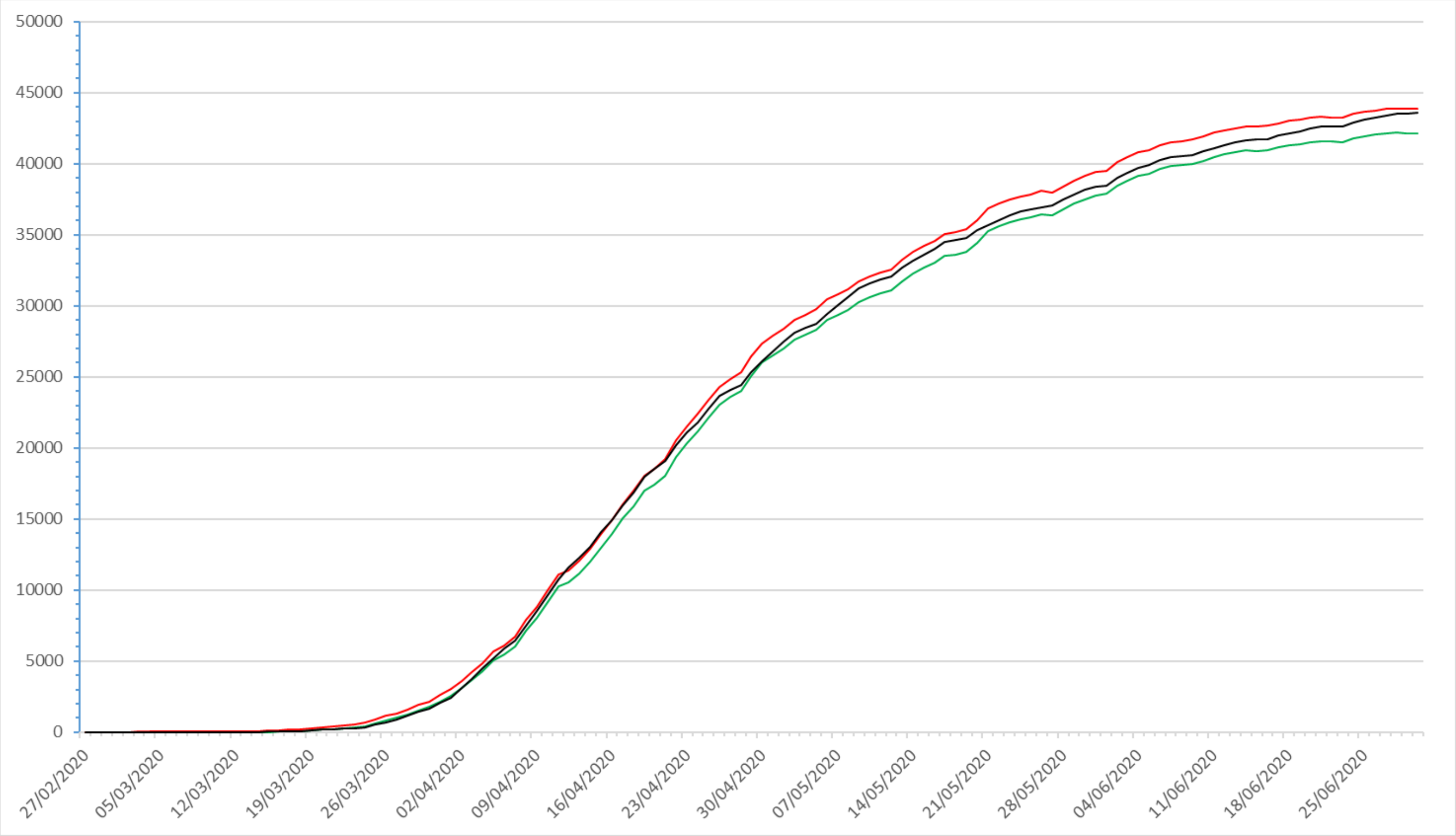
$$\hat{p}_U(n, k, 0.95) \leq \frac{k + 3.255}{n + 2.706} + 1.645\sqrt{\frac{nk - k^2 + 2.578n + 0.196k - 3.617}{n(n + 2.706)^2}}$$

**** The response variables can be fixed as LP/MILP constraints for a fixed confidence ****

Proportion Tracking (Discrete Population)



Response Forecast (Discrete Population)



Next Steps…

- Revisit data from DR-BoB Demonstrations;
- Analyse data from REACT Demonstrations;
- Revisit work on aggregated DR (utility perspective);

Heuristic Scheduling of Multiple Smart Home Appliances: Utility Planning Perspective

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Abstract—**Electric utilities are increasingly incorporating Demand Side Management (DSM) approaches in their energy networks to help compensate for increased levels of uncertainty arising from renewable energy production. Demand Response (DR) is one such approach. DR aims to encourage shifts in residential load by using pricing signals and dynamic tariff mechanisms which are provided in real-time by the utility company. The goal is to shift energy consumption patterns to off-peak times and hence reduce the Peak-to-Average Ratio (PAR) of the daily electricity demand. In this paper, the effects of multiple households using a fast heuristic algorithm for scheduling smart appliances is simulated from a utility planning perspective. It explores the aggregated response of the de-centralized heuristic algorithms to events signaled by the utility, when the primary focus of each heuristic is upon minimization of end-user economic costs. The performance of the heuristic algorithm for DR events under normal and stringent conditions is explored under simulation. Results confirm that the aggregated demand can potentially respond to DR signals, although the choice of price signals plays a major role in the depth and nature of the response and requires further investigation.**

Keywords—Electric Utility, Demand Response, Heuristic algorithm, Utility planning, Appliance scheduling.

I. Introduction

Insufficient investment in the ageing electricity infrastructure along with increasing penetration of distributed renewable resources has made it more difficult to both meet increasing system loads and match electricity supply with demand [1]. This has placed an additional responsibility on utilities to incorporate Demand Side Management (DSM) approaches in their energy networks to reduce peak loads and match capacity of supply with demand. From the consumer side, scheduling of controllable loads (such as smart appliances) with the help of energy management decision support systems can help to achieve DSM in general, and also can assist with Demand Response (DR) for event handling. Additional mechanisms such as ancillary services (AS) [2] are also needed to regulate supply and demand and also respond to contingencies, for example during a sudden loss of transmission of electric power from utilities to the consumers. AS has potential benefits for consumer demand response participation. Such benefits include the availability of reliable resources to system operators; flexibility to manage uncertainty events as a result of increasing integration of renewable generations to the grid [2] etc. These are aimed at enhancing energy system efficiency and helps to prevent grid instability. In conjunction, utility companies can ensure proper planning, implementation and monitoring of DR activities designed for efficient utilization of the existing infrastructure network while reducing the cost of grid upgrades.

Our main contribution in this paper is to provide an initial exploration of the extent to which a heuristic algorithm for household load scheduling can help shift aggregated demand in response to utility DR events affecting the wider grid. Heuristic scheduling algorithms can be used to solve residential energy cost optimization problems; they can very quickly find 'good' solutions. An exhaustive search algorithm, on the other hand, can find the best solution: but it may take large amounts of computational effort to do so. We have previously described an efficient heuristic optimizer which is simple enough to be implemented on a small embedded processor to autonomously schedule controllable smart home appliances [3] [4]. The principal goal of the heuristic is to minimize a resident's electricity bill in the presence of varying utility price signals. Consequently, the utility company could adjust the pricing signals and energy capacity provided in each timeslots to help plan their actions. Hence, this decision making process between consumers and the utility company could be seen as a communication pathway aimed at achieving demand response.

The motivation for this work is as follows. Various DR techniques such as, peak load curtailment for unexpected DR events [5] [6], direct load control [7] and price responsive demand [8] have all been employed in the past few years for reducing peak demand. However, such techniques have limitations in terms of the required ability of the utility company to control the residential smart appliances remotely. As a result, utilities are adopting incentive based mechanisms to encourage residential customers to conserve energy and reduce peak demand. They advertise dynamic pricing such as Critical Peak Pricing (CPP) [9], Real time pricing (RTP) [10-12] Time of use pricing (TOUP) [13], etc. One of the barriers to enabling a critical investigation to different pricing schemes and their subsequent appraisal for use in future smart grid has been the complexity of the residential load-scheduling problem, which is known to be NP-hard [14]. Therefore, the use of our near-optimal and extremely low-overhead heuristic algorithm opens a pathway for large-scale simulations and investigations of the impact of pricing schemes on residential DR. In this paper, we begin to document such simulations on the behavior of multiple instances of the algorithm in response to unexpected events affecting the wider grid. Overall, our test results confirm that the heuristic rapidly responds to DR signals and produces the desired responses from numerous households in synchronicity, although the choice of price signals plays a major role in the depth and nature of the response.

Thank you for the invitation to speak!

Questions…