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Quality of Service (QoS) nella Smart Grid

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Non pubblicare o diffondere senza questo avviso.

QoS Routing in Smart Grid

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IEEE Globecom 2010

Abstract*—Smart grid is an emerging technology which is able* to control the power load via price signaling. The communication between the power supplier and power customers is a key issue in smart grid. Performance degradation like delay or outage may cause significant impact on the stability of the pricing based control and thus the reward of smart grid. Therefore, **a QoS mechanism is proposed for the communication system in smart grid,** which incorporates the derivation of QoS requirement and applies QoS routing in the communication network. For deriving the QoS requirement, **the dynamics of power load and the load-price mapping are studied.** The corresponding impacts of different QoS metrics like delay are analyzed. Then, the QoS is derived via an optimization problem that maximizes the total revenue. Based on the derived QoS requirement, a simple greedy (*venale, basato sul guadagno*) QoS routing algorithm is proposed for the requirement of high speed routing in smart grid. It is also proven that the proposed greedy algorithm is a *K-approximation. Numerical simulation* shows that the proposed mechanism and algorithm can effectively derive and secure the communication QoS in smart grid.

Come assicurare i requisiti desiderati nella Smart Grid

La Smart Grid è una rete in cui per ciascun tratto (lato del grafo che la rappresenta) si può calcolare il costo di un servizio che garantisce un certo requisito.

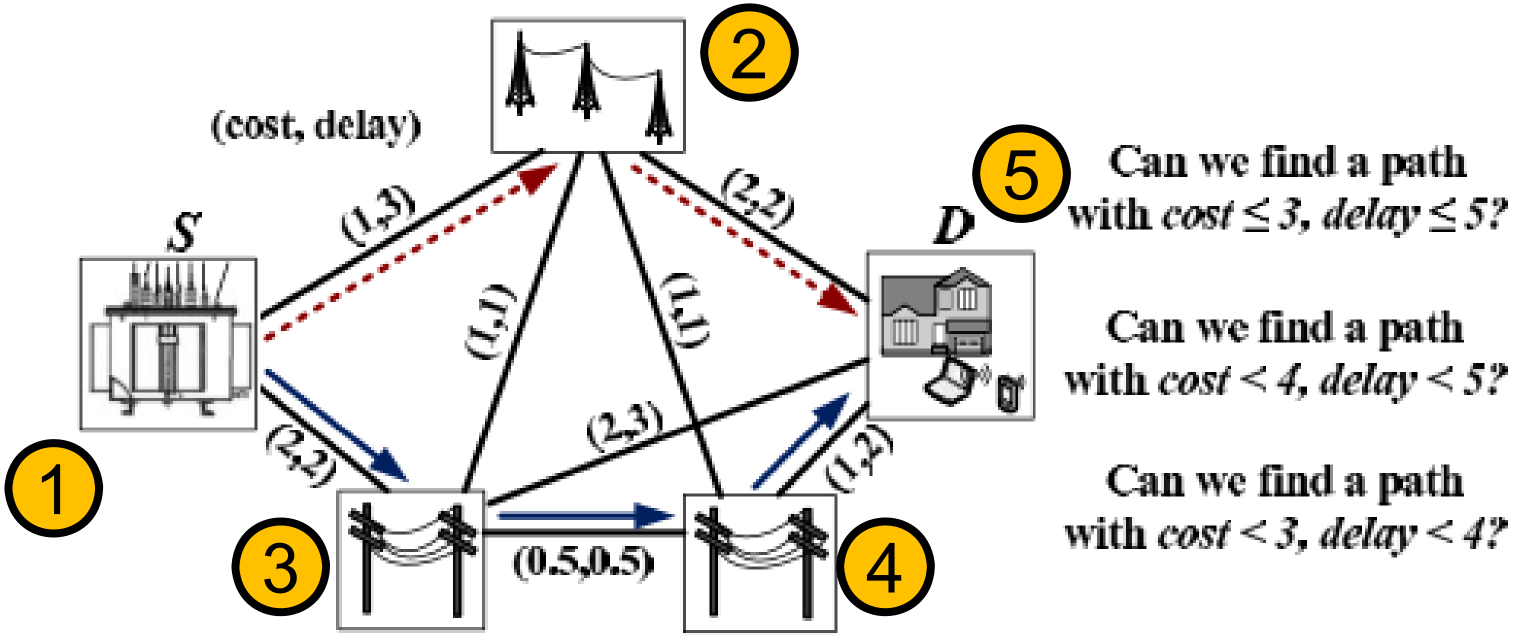


Fig. 3: Illustration of the MCR problem

Perché è necessario QoS per la Smart Grid?

In a Smart Grid, one of key challenge is **how to adapt the communication network to the context of power price transmission**.

The data flow of power price cannot be elastic (***no Best Effort strategy***) since it should be **realtime**; otherwise, it may incur a significant loss if the expired power price is used.

Therefore**, the data transmission of power price must be equipped with quality of service (QoS)** guarantee.

I quesiti di QoS relativi alla Smart Grid

- ***How to define the QoS requirement in the context of smart grid?***
- ***How to ensure the QoS requirement from the home appliance in the communication network?***

This paper proposes **one** *QoS system for smart grid.*

The proposed QoS framework **plays the role of interface between the power market and the communication networks**.

Once a set of reasonable QoS metrics ***(criteri di misura)*** can be derived in the context of smart grid, many QoS ensuing approaches can be applied to guarantee the performance gain introduced by the technology of smart grid.

L’impostazione del problema

Scelta dei parametri significativi

- For simplicity, we study only two QoS parameters, namely the delay (***ritardo***) and outage (***fuori servizio***) probability.
- We first introduce the mechanism of power price based on the dynamics of load.
- Then, we build a reward (***incentivi***) system for the home appliance based on the power price and the utility function of the appliance, thus obtaining the impact of delay and outage on the reward of home appliance.
- Finally, the QoS requirement is derived by optimizing the reward.

Il modello della Smart Grid

Con attenzione ai parametri significativi per QoS

We assume that a home appliance receives power price from the power market.

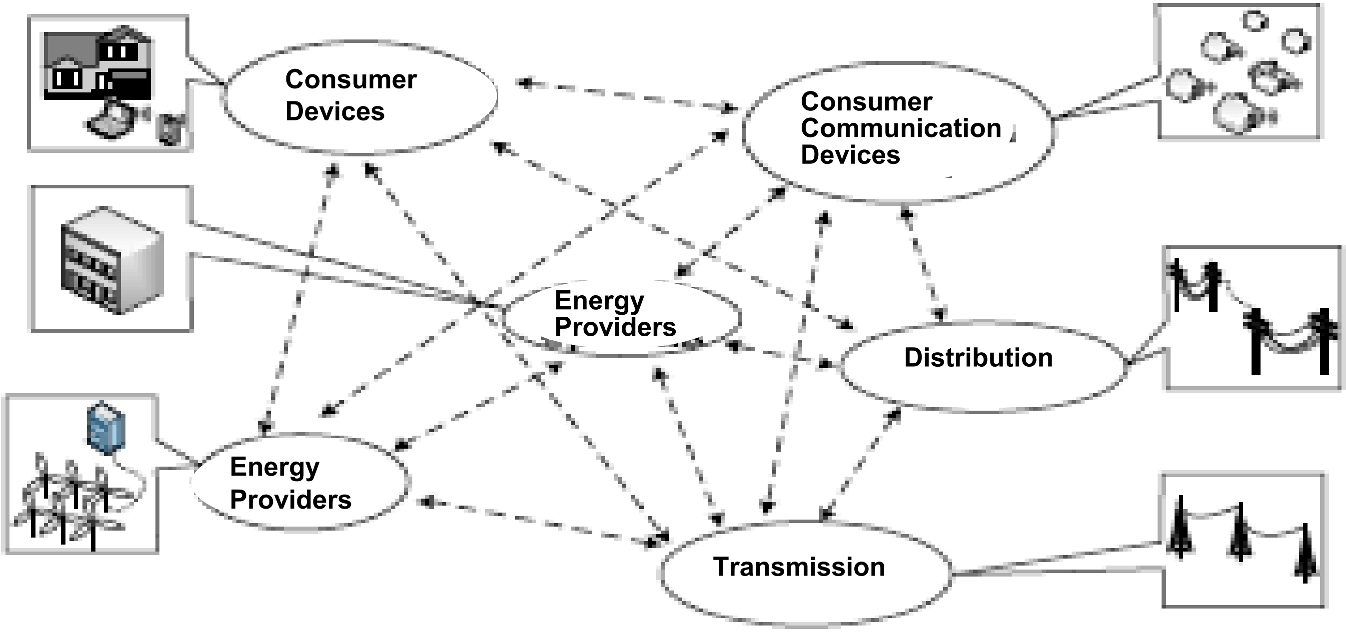
- A QoS requirement is sent from the home appliance to the control center of the communication network.
- Then, the control center assigns one or more route for the home appliance to guarantee the QoS requirement.

Smart devices, such as smart meter, and electricity generator can be viewed as the nodes throughout a network. All the transmission medium (wireless, power line, GPRS, radio etc), form the links in a network.

The whole infrastructure of smart grid can be represented by a communication network structure, which is designed to optimize a smart grid investment.

Il modello della Smart Grid

Con attenzione ai parametri significativi per QoS



It is worth noting that smart grid is a heterogeneous network (various equipments, with different resource limits, such as computing power, storage capability, are integrated in the grid.

To provide QoS-aware routing for smart grid, we must consider the heterogeneity of the network and provide solutions that could be applied for all the devices in the networks.

Determinazione dei requisiti QoS

A QoS requirement usually includes specifications like average delay, jitter and connection outage probability.

To derive the QoS requirement, the following problems should be addressed in the study:

• How to describe the probabilistic dynamics of the power

system?

• How to evaluate the impact of different QoS specifications on the smart grid system? For example, how does a long communication delay affect the system performance?

• How to derive QoS requirement due to the corresponding impact?

Valutazione dell'andamento dinamico dei prezzi

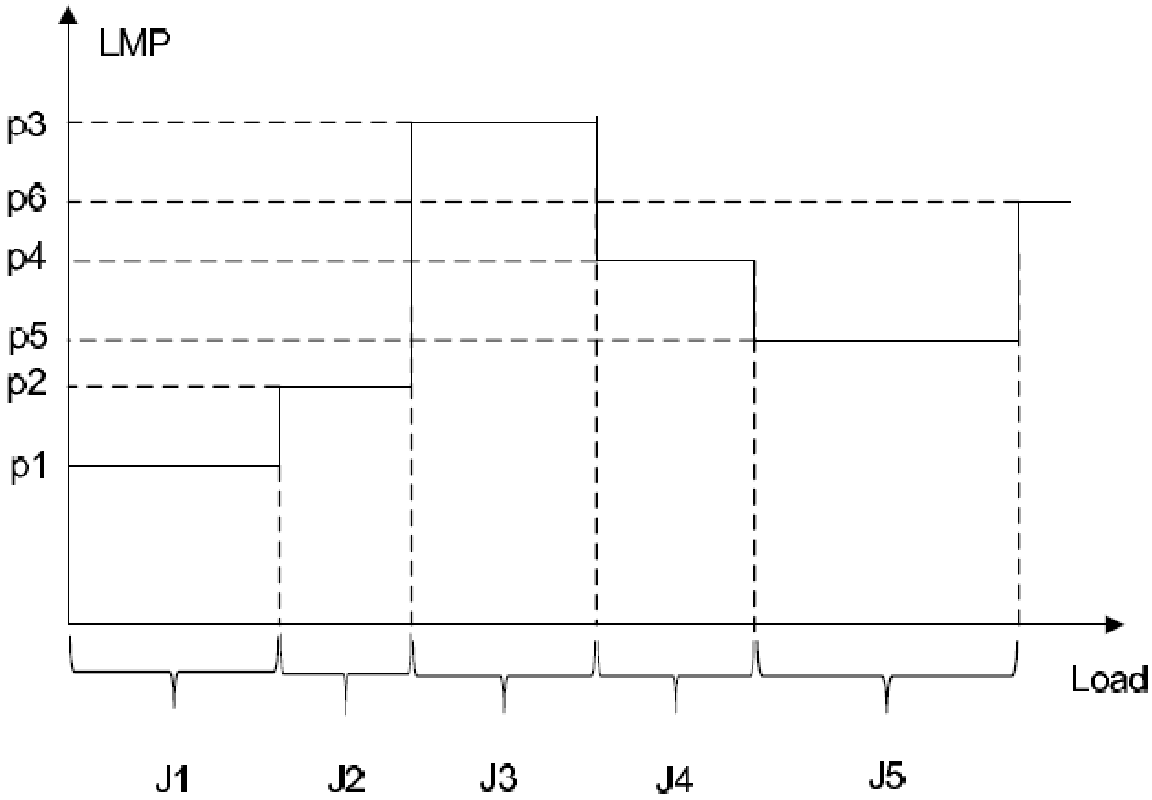
Power price is typically determined by Locational Margin Price (LMP) driven by the load which varies with time.

Locational Margin Price. *Il costo di un kW di energia incrementale richiesto in un dato nodo, che dipende istante per istante dalla situazione complessiva della rete, e in particolare è legato al carico richiesto in quel nodo.*

A constrained optimization problem can be used to derive the LMP from the load and other parameters, where the Lagrange factors of the constraints are considered as prices.

In practical systems, we can use a piecewise curve, as illustrated in Fig. 2, to accomplish the mapping between the load and the price. Note that, we have finite numbers of prices, denoted by *Q, in Fig. 2. Therefore, we denote by q1, q2, ..., qQ these* prices. The intervals of loads corresponding to the prices *q1, ..., qQ are denoted by J1, ..., JQ, respectively. We assumed* that the load is uniformly distributed within the corresponding interval given the price.

Relazione tra prezzo e carico



Relazione (curva costante a tratti) fra i livelli di carico (J_i) e prezzi (p_i). Le variazioni si verificano in corrispondenza dei livelli critici di carico dovuti al raggiungimento di diversi tipi di limiti (termici, di capacità) per cui si ha una variazione del prezzo sul mercato.

Variazione del carico

Il carico è modellizzato come una funzione casuale dipendente da vari fattori legati alla rete. In questo caso utilizziamo la seguente espressione:

$$f(D_t) = \frac{\exp\left(-\frac{(D_t-\mu_t)^2}{2\sigma_t}\right)}{\int_0^{D_{\max}} \exp\left(-\frac{(y-\mu_t)^2}{2\sigma_t}\right) dy}, \qquad (1)$$

D_t è il carico (costante) durante la finestra temporale t (slot t)

D_{max} è il carico massimo possibile

μ_t **è il valore atteso**. Se D_0 è il valore effettivo misurato del carico nel tratto iniziale (t=0), assumiamo $\mu_t = D_0$

σ_t **è la varianza** della funzione, che si assume come dipendente in modo lineare dal tempo; $\sigma_t = \theta t$ (moto browniano)

Impatto del ritardo sui costi (1)

At time slot t, the power price and power consumption are denoted by p_t and x_t, respectively. We assume a time-invariant utility function for the power consumption and denote it by U(xt)

The decision of power consumption is based on the known power price, which means that x_t is a function of p.

For simplicity, we assume that the optimal power consumption level maximizes the following metric:

$$x_t(p) = \arg\max_x \left(U(x) - px \right), \qquad (2)$$

where p is the price adopted by the home appliance. It could be different from the true value due to delay.

Impatto del ritardo sui costi (2)

We assume that *U* is an increasing, strictly concave and continuously differentiable function. We also assume that the first order derivative of U, denoted by $\dot{U}$, ranges from ∞ to 0. Based

on these assumptions, the optimal power consumption level is thus given by $x_t(p)=\dot{U}^{-1}(p)$, which is derived from the first order condition of optimality, i.e. :

$\dot{U}(x) - p = 0$

Impatto del ritardo sui costi (3)

Suppose that the communication delay is d time slots. Then, at time slot t, the price used for optimizing the power consumption level is p (t-d).

Hence, the cost incurred by the communication delay, as a function of the delay, is given by:

$$\begin{aligned} C(d) &= E\left[U(x(p_t)) - p_t x(p_t)\right. \\ &- \left.\left(U(x(p_{t-d})) - p_t x(p_{t-d})\right)\right], \end{aligned} \tag{3}$$

where the expectation is over all realizations of the power price and can be computed using the probabilistic dynamics of the power price discussed in Section III. A

Impatto del fuori servizio sui costi

It is also possible that the communication link experiences an outage such that the home appliance cannot obtain the real time power price. In such a situation, the home appliance can only use a default power price, which is independent of the time. We assume that the default power price equals the average power price, which is denoted by $\bar{p}$. Then, the expected loss incurred by the outage is given by

$$L(\zeta) = \zeta E\left[U(x(p_t)) - p_t x(p_t) - (U(x(\bar{p})) - p_t x(\bar{p}))\right], \quad (4)$$

where ζ is the outage probability.

How to derive QoS requirement due to the delay

Calcolo del ritardo “ottimale” tenendo conto che anche assicurare un ritardo minimo *d* ha dei costi (*P(d)*)

$$d^* = \arg\min_d \left(C(d) + P(d)\right) . \qquad (5)$$

In cui:

C(d)= costo dovuto alla presenza del ritardo (vedi *(3))*

P(d)= Prezzo necessario per assicurare che il ritardo non sia superiore a *d*.

How to derive QoS requirement due to the outage

Anche assicurare che la rete abbia una probabilità di guasto non superiore a ζ ha un costo (tassa T(ζ)).

Pertanto **il valore ottimale di ζ** è dato da:

$$\zeta^* = \arg\min_{\zeta} \left(\zeta L(\zeta) + T(\zeta)\right). \quad (6)$$

Si può definire una funzione ottimale dei due valori congiunti:

$$(d^*, \zeta^*) = \arg\min_{\lambda,\zeta}(1-\zeta)C(d) + \zeta L(\zeta) + P(d) + T(\zeta). \quad (7)$$

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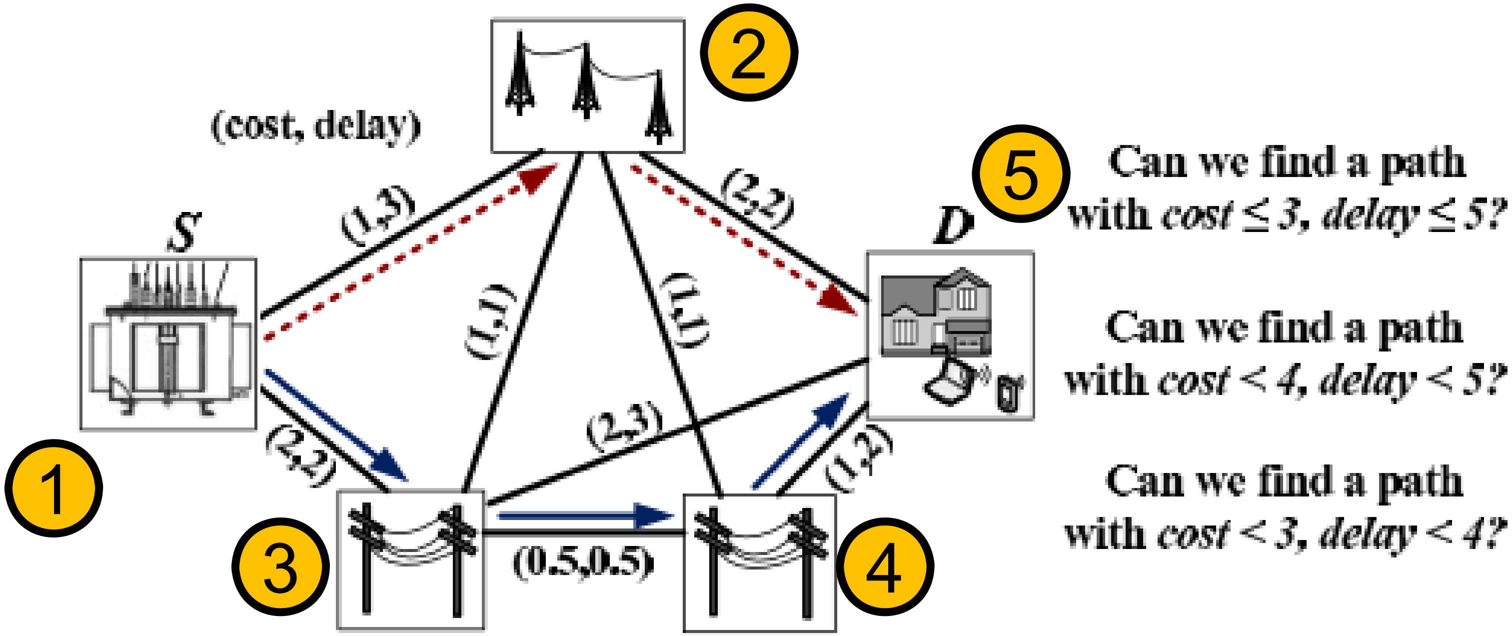

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Teoria dei grafi e Routing

Il calcolo sistematico e ottimale dei percorsi che assicurano determinati requisiti, dati i relativi vincoli è sviluppato analiticamente e numericamente attraverso la Teoria dei grafi e gli algoritmi di Routing.