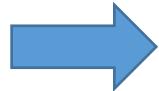


Pilotage décentralisé des flexibilités pour les systèmes électriques

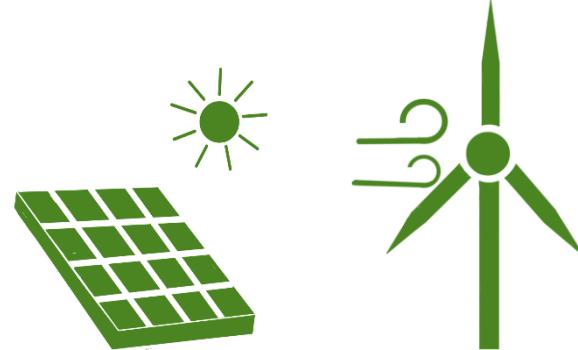
Nadia Oudjane
(EDF, FIME)

New context

- Variable renewable resources integration



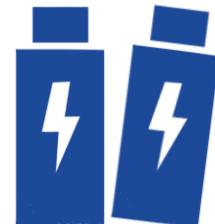
Need for new flexibilities



- Progress in smart technologies



Opportunities for new flexibilities



New issues

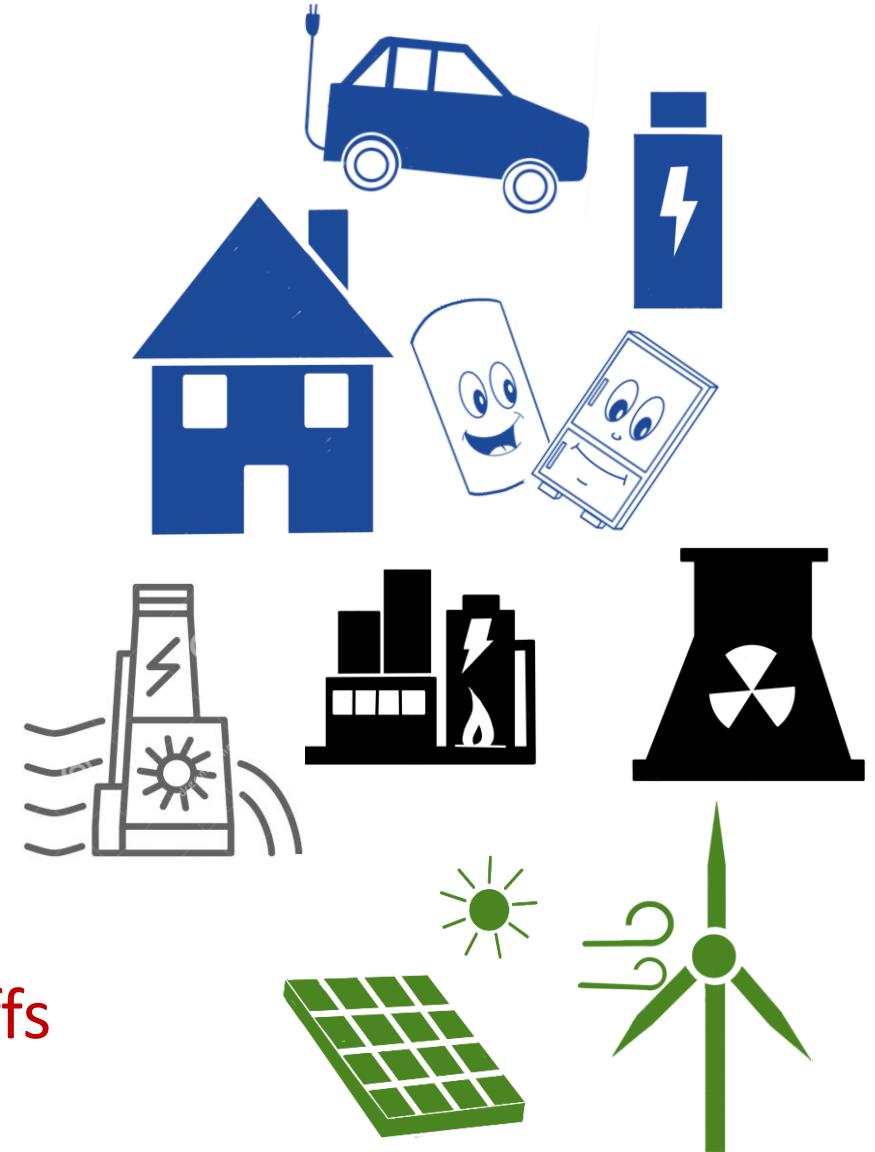
- **Optimally manage** these new flexibilities

- ✓ Together with conventional flexibilities
 - ✓ Take into account their **specific features**

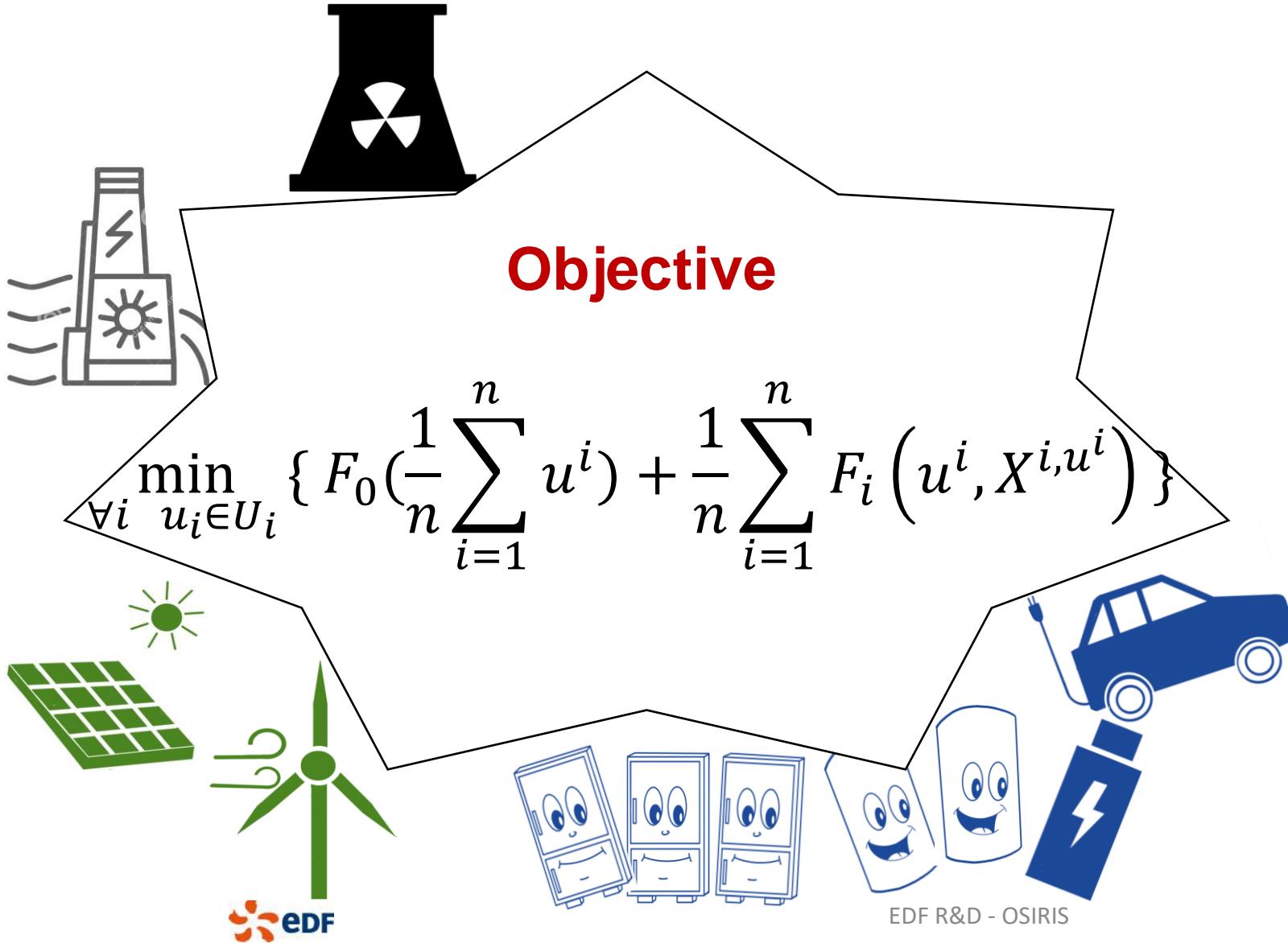
- ✓ (local constraints, uncertainties, privacy, ...)

- Control in **real time** in a distributed way

- **Encourage** flexible agents by **incentives** and tariffs



Optimal management



- Non convexities
- Coupling constraints
- Uncertainties
- Large number
- **Distributed approach**

Aggregation / Disaggregation

$$\min_{\forall i \ u_i \in U_i} \left\{ F_0 \left(\frac{1}{n} \sum_{i=1}^n u^i \right) + \frac{1}{n} \sum_{i=1}^n F_i \left(u^i, X^{i,u^i} \right) \right\}$$

- Consider an approximate model on the aggregate

$$\bar{u} = \frac{1}{n} \sum_{i=1}^n u^i, \quad \bar{X} = \frac{1}{n} \sum_{i=1}^n X^i$$

In general requires symmetry or specific dynamics & costs

- **Aggregator problem**

$\forall t \in [0, T], \forall k \in [M],$

$$\begin{cases} X_t^{(k)} = \frac{1}{N_k} \sum_{j=1}^{N_k} x_0^{(k,j)} + \int_0^t (\alpha_s^{(k)} u_s^{(k)} + \beta_s^{(k)} X_s^{(k)} + \bar{\gamma}_s^{(k,N)}) ds, \\ Y_t^{(k)} = \mathbb{E}_t \left[\rho^{(k)} (X_T^{(k)} - \bar{x}_T^{\text{f},(k,N)}) + \int_t^T (\beta_s^{(k)} Y_s^{(k)} + \nu_s^{(k)} (X_s^{(k)} - \bar{x}_s^{\text{ref},(k,N)})) ds \right], \\ \mu_t^{(k)} (u_t^{(k)} - \bar{u}_t^{\text{ref},(k,N)}) + \mathcal{L}'_x \left(t, \sum_{l=1}^M \pi^{(l)} u_t^{(l)} + \bar{P}_t^{\text{load},(N)} - P_t^{\text{prod}} \right) + \alpha_t^{(k)} Y_t^{(k)} = 0. \end{cases}$$

- **Agent problem**

$$\begin{cases} \Delta X_t = x_0^{(k,i)} - \bar{x}_0^{(k,N)} + \int_0^t (\alpha_s^{(k)} \Delta u_s + \beta_s^{(k)} \Delta X_s + \gamma_s^{(k,i)} - \bar{\gamma}_s^{(k,N)}) ds, \\ \Delta Y_t = \mathbb{E}_t \left[\rho^{(k)} (\Delta X_T - x_T^{\text{f},(k,i)} + \bar{x}_T^{\text{f},(k,N)}) + \int_t^T (\beta_s^{(k)} \Delta Y_s + \nu_s^{(k)} (\Delta X_s - x_s^{\text{ref},(k,i)} + \bar{x}_s^{\text{ref},(k,N)})) ds \right], \\ \mu_t^{(k)} (\Delta u_t - u_t^{\text{ref},(k,i)} + \bar{u}_t^{\text{ref},(k,N)}) + \alpha_t^{(k)} \Delta Y_t = 0. \end{cases}$$

Aggregation/Disaggregation

$$\min_{\forall i} \min_{u_i \in U_i} \left\{ F_0 \left(\frac{1}{n} \sum_{i=1}^n u^i \right) \right\}$$

- Learn an approximate model on the aggregate

$$\bar{u} = \frac{1}{n} \sum_{i=1}^n u^i$$

Deterministic case with polyhedral constraints [JacquotEtal20]

Global Criteria

$$\forall i \min_{u_i \in U_i} F_0(\sum_{i=1}^n u_i)$$

Central Actor

(aggregator)

Ideal aggregate constraint set

$$U_0^* := \{\sum_i u_i \mid u_i \in U_i\}$$

Constraint update
 $U_0 \rightarrow U_0 \cap C \supset U_0^*$



Profile update
 $v_0 = \operatorname{argmin}_{v \in U_0} F_0(v)$

New cut
 C



Privacy Preserving computation of a violated cut C

Local Actors
(flexibilities)

Disaggregation not possible



Distributed Disaggregation of v_0 on U_i
(Alternate Projection)

Aggregate profile v_0

Mean-field approximation

$$J(u) = E[F_0(\frac{1}{n} \sum_{i=1}^n u^i)] + \frac{1}{n} \sum_{i=1}^n E[F_i(u^i, X^{i,u^i})]$$

n to n interactions



$$\tilde{J}(u) = F_0(\frac{1}{n} \sum_{i=1}^n E(u^i)) + \frac{1}{n} \sum_{i=1}^n E[F_i(u^i, X^{i,u^i})]$$

Interactions **between agents** is approximated by the interactions of each agent **with marginal distributions**

A decentralized solution *using ditributed optimization*

[SeguretEtal20]

- Each agent locally optimize her revenue w.r.t. the price λ

$$u^i(\lambda) := \underset{u^i \in U_i}{\operatorname{argmin}} \{ E[F_i(u^i, X^{i,u^i}) + \langle \lambda, u^i \rangle] \}$$

- Under convexity assumptions, there exists λ^* implying for each agent **the optimal response**
- λ^* depends on the optimal aggregate... **link with games**

Global Criteria

$$\forall i \min_{u^i \in U_i} E[F_0\left(\frac{1}{n} \sum_{i=1}^n u^i\right) + \frac{1}{n} \sum_{i=1}^n F_i(u^i, X^{i,u^i})]$$

Central Actor

(aggregator)

Constraint dualization

$$\begin{aligned} & \min_{v, u^i \in U_i} F_0(v) + \frac{1}{n} \sum_i^n E[F_i(u^i, X^{i,u^i})] \\ & \text{s.t. } v = \frac{1}{n} \sum_{i=1}^n u^i \end{aligned} \quad (\lambda)$$

Aggregate Profile

$$\frac{1}{M} \sum_{i \in I} u_k^i$$



Price update

$$\begin{aligned} & \min_v \{F_0(v) - \langle \lambda, v \rangle\} \\ & \lambda \rightarrow \lambda + \rho \left(\frac{1}{M} \sum_{i \in I} u_k^i - v \right) \end{aligned}$$

Price λ



Local Actors

(flexibilities)



Profiles update

Generate a set I of M indexes uniformly in $[1, n]$

$$\text{Compute } u^i(\lambda) := \min_{u^i \in U_i} \{E[F_i(u^i, X^{i,u^i}) + \langle \lambda, u^i \rangle]\}$$

$$\text{Generate independent realizations } u_k^i := u^i(\lambda)(\omega_k^i)$$

Incentives design and games

[JacquotEtal17, AidEtal18, ElieEtal20, AusselEta20, LiuEtal20]

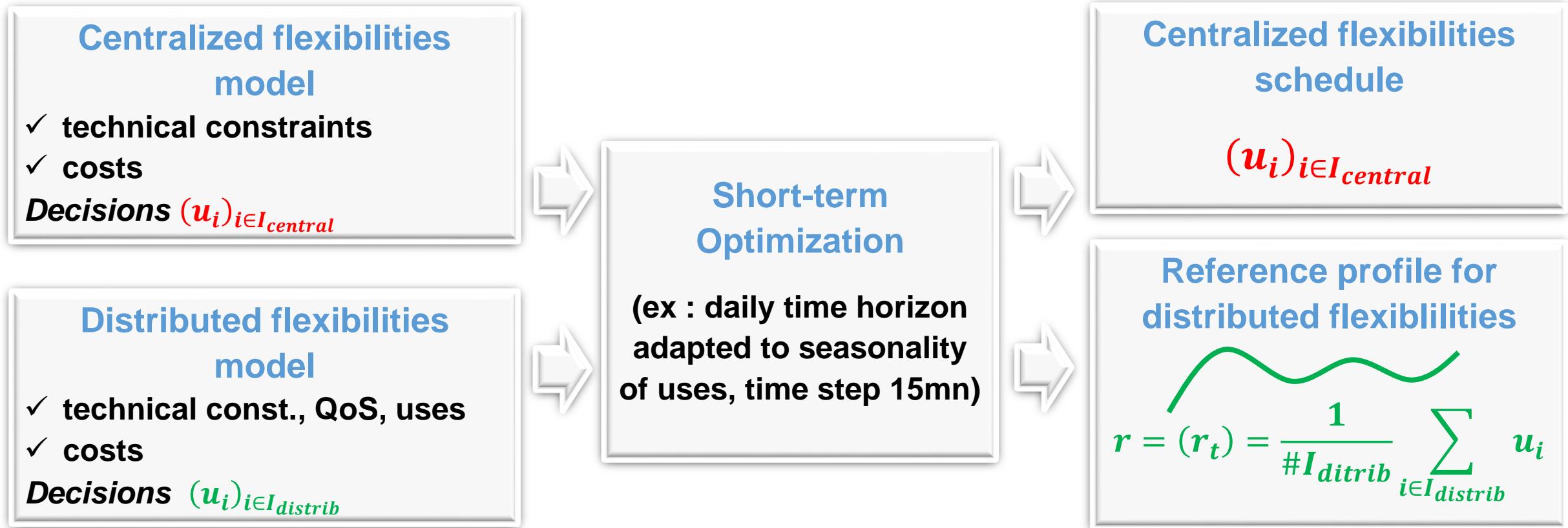
- **Comment inciter les consommateurs à participer** à l'équilibre du système / portefeuille ?
⇒ **Imaginer des fonctions de rémunération/tarification** des agents telles que l'équilibre du jeu résultant soit bon pour l'objectif du système / portefeuille

=>**Chaque agent/joueur minimise sa facture**

$$\min_{u^i} \varphi_i(u^i, X^{i,u^i}, \frac{1}{n} \sum_j u^j)$$

Une architecture en deux temps : *J-1* puis *temps réel*

1. En *J-1* : « Flexibility Commitment Problem » (FCP) : calcul d'une cible (r_k) atteignable

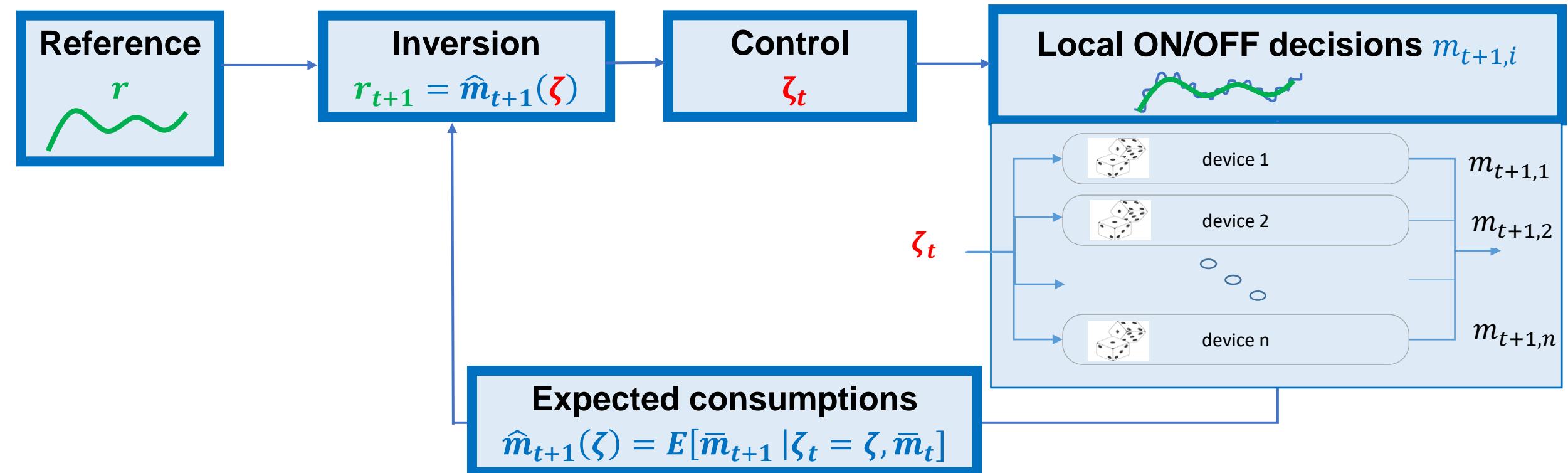


2. En temps réel : contrôle automatique « meanfield Inversion »

Contrôle distribué temps réel

[BusicEtMeyn16, BendottiEtal21]

Contrôle automatique : PI (Proportionnel Intégral), LQR, meanfield Inversion ...



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