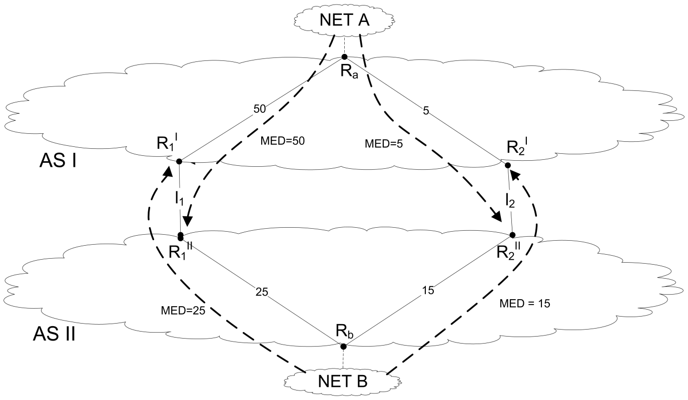

Fig. 2. Peering MED interaction example

TABLE I
A DUMMY GAME.

I \ II	l_1	l_2
l_1	**(50,25)**	**(5,25)**
l_2	**(50,15)**	**(5,15)**

TABLE II
A CLUBMED GAME.

I \ II	l_1	l_2
l_1	(100,50)	(55,40)
l_2	(55,40)	**(10,30)**

III. THE CLUBMED FRAMEWORK

We model the MED signalling between peering ASs as a non-cooperative game wherein peering ASs can implicitly coordinate their routing strategies. As of our knowledge, this is the first attempt in this direction. We nickname it the ClubMED (Coordinated MED) framework. For the sake of clarity, we first start with a simple but unrealistic model with 2 peering links and bidirectional routing costs. Then, we generalize it to the complete realistic generic form, integrating IGP-WO operations and peering link congestion controls.

A. MED-based coordination

In Fig. 2, AS I and AS II are two peers. NET A and NET B are two destination networks whose flows are supposed to be equivalent (e.g., w.r.t. the bandwidth), so that their path cost can be fairly compared and their routing coordinated. Each peer would desire to minimize its routing cost for the incoming flow. The routing costs are indicated in Fig. 2. AS I and AS II announce NET A and NET B with the MED attribute set to the routing cost by the corresponding egress router. The peering interaction can be described with the strategic form in Table I. The cost of each player is the MED of the route it announced, then selected by the peer. Each AS has the choice if routing the outgoing flow on link 1 (l_1) or on link 2 (l_2).

In non-cooperative games, a Nash equilibrium is to be selected by rational players because it yields stability to the strategy profile, the players not being motivated in deviating from it [11]. In Table I every profile is a Nash Equilbrium. We have a dummy game: whatever the other player's strategy is, there is no gain in changing its strategy. This somehow shows that a simple MED usage is dummy for such a case. We should enrich the dummy game considering the egress cost of the flow in the opposite direction, thus summing the routing costs of

TABLE III
2-LINK CLUBMED GAME, SUM OF TWO GAMES WITH POTENTIAL.

I \ II	l_1	l_2
l_1	(c_1^I, c_1^{II})	(c_1^I, c_2^{II})
l_2	(c_2^I, c_1^{II})	(c_2^I, c_2^{II})

+

I \ II	l_1	l_2
l_1	(c_1^I, c_1^{II})	(c_2^I, c_1^{II})
l_2	(c_1^I, c_2^{II})	(c_2^I, c_2^{II})

$$\begin{pmatrix} 0 & c_1^{II} - c_2^{II} \\ c_1^I - c_2^I & c_1^{II} - c_2^{II} + c_1^I - c_2^I \end{pmatrix} \quad + \quad \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$$

both the flows in opposite directions for each AS. However, in this way we would assume that both the NET A $\leftrightarrow$ NET B flows pass through the peering AS I-AS II, which would not be realistic (BGP policies can induce asymmetric routing). Moreover, traffic flows to care of are typically between content and "eyeball" providers (with a lot of clients) [8], which would not make the A $\leftrightarrow$ B flows equivalent. Instead of single prefix network, we should consider *destination cones* (i.e., groups of network prefixes). The cone prefixes shall belong to direct customers or stub ASs, whose entry point in a peer network is likely to be unique (even if they are multi-homed, they should have chosen backbone-disjoint providers, referring to disjoint core carriers; see Sect. IV for more practical aspects).

Therefore, in the complete strategic form in Table II, each AS sums the costs due to the two community A $\leftrightarrow$ community B flows. (l_2, l_2) is the unique Nash equilibrium. Hence, rational ASs would implicitly coordinate as suggested by (l_2, l_2), which in this case corresponds to accept the suggestion to routing the flow toward the neighbor's preferred egress router, and moreover to route alike hot-potato routing. Swapping e.g. the R_a-R_1^I and R_b-R_2^I IGP path costs (in Fig. 2) it is easy to verify that the Nash equilibrium is (l_1, l_2) with costs (55,40). In this case (l_2, l_1) has costs equal to (l_1, l_2), but it is not an equilibrium; ClubMED still behaves as hot-potato routing, but in this case the MEDs of AS I are not respected by AS II.

Let c_i^I and c_i^{II} be the IGP costs between R_a and R_b (resp.) and l_i, $i \in E$. For the generic case of two inter-AS links, the cost vector for the strategy profile (l_i, l_j), $i, j \in \{1, 2\}$, is thus ($c_i^I + c_j^I$, $c_i^{II} + c_j^{II}$). The resulting ClubMED game (Table III) can be described as $G = G_s + G_d$, sum of two games. $G_s = (X, Y, f_s, g_s)$, a selfish game, purely endogenous, where X and Y are the set of strategies and $f_s, g_s : X \times Y \to \mathbf{N}$ the cost functions, for AS I and AS II (resp.). In particular, $f_s(x, y) = \phi_s(x)$, where $\phi_s : X \to \mathbf{N}$, and $g_s(x, y) = \psi_s(y)$, where $\psi_s : Y \to \mathbf{N}$. $G_d = (X, Y, f_d, g_d)$, a dummy game, of pure externality, where $f_d, g_d : X \times Y \to \mathbf{N}$ are the cost functions for AS I and AS II (resp.). In particular, $f_d(x, y) = \phi_d(y)$, where $\phi_d : Y \to \mathbf{N}$, and $g_d(x, y) = \psi_d(x)$, where $\psi_d : X \to \mathbf{N}$. G_s is a cardinal potential game [14], i.e., the incentive to change players' strategy can be expressed in one global function, a potential function (P_s), and the difference in individual costs by an individual strategy move has the same value as the potential difference. G_d can be seen as a potential game too, with null potential (P_d). G has thus a potential $P = P_s + P_d = P_s$. In the bottom of Table III we report P_d