$$\text{minimize} \quad \sum_{(i,j)\in A_1} c_{ij1}x_{ij} + \sum_{(i,j)\in A_1} c_{ij1}y_{ij} + \sum_{r\in K_2}\sum_{(i,j)\in A_2} c_{ij2}z_{ijr}$$

subject to

Constraints for FEV

Flow conservation for FEV at each parking node

$$\sum_{(i,j)\in A_1} x_{ij} = \sum_{(j,i)\in A_1} x_{ji}, \quad i \in N_p \tag{1}$$

$$\sum_{(i,j)\in A_1} x_{ij} \leq 1, \quad i \in N_p \tag{2}$$

$$\sum_{(j,i)\in A_1} y_{ji} + \sum_{(j,i)\in A_1} y_{ij} \leq 1, \quad i \in N_p \tag{3}$$

$$y_{ij} \leq x_{ij}, (i,j) \in A_1 \tag{4}$$

Flow conservation for FEV at depot

$$\sum_{(0,j)\in A_1} x_{0j} = \sum_{(j,0')\in A_1} x_{j0'} = 1 \tag{5}$$

$$\sum_{(0,j)\in A_1} y_{0j} = \sum_{(j,0')\in A_1} y_{j0'} = 0 \tag{6}$$

The capacity constraints for the FEV

$$\sum_{p\in N_p} w_p \leq Q_0 \tag{7}$$

Constraints for Mobile Microhub

Constraints for initial parking place

$$\sum_{(i,j)\in A_1} y_{ij} \leq p_i, \quad i \in N_p \tag{8}$$

$$\sum_{(i,j)\in A_1} y_{ij} \leq 1 - p_j, \quad j \in N_p \tag{9}$$

$$w_p \leq Q_1(1 - \sum_{(p,j)\in A_1} y_{pj}), \quad p \in N_p \tag{10}$$

Link the 1st and 2nd echelon and impose that the total flow from the depot to MM equals to total demand served from MM

$$w_p = \sum_{(p,j)\in A_2} f_{pj}, \quad p \in N_p \tag{11}$$

Capacity constraints for MM (The freight flow from depot to MM can only be positive if parking node is used)

$$w_p \leq Q_1 \sum_{(i,p)\in A_1} x_{ip}, \quad p \in N_p \tag{12}$$

$$w_p \leq Q_1 (\sum_{(i,p)\in A_1} y_{ip} + p_p), \quad p \in N_p \tag{13}$$

Constraints for SEV(Multiple Robots, each one dispatched once)

Flow conservation at parking nodes and customer nodes

$$\sum_{(i,j)\in A_2} z_{ij}^r = \sum_{(j,i)\in A_2} z_{ji}^r, \quad i \in N_p \cup N_c, r \in K_2 \tag{14}$$

$$\sum_{r\in K_2} \sum_{(p,j)\in A_2} z_{pj}^r \leq |K_2|, \quad p \in N_p \tag{15}$$

$$\sum_{(p.j)\in A_2} z_{pj}^r \leq 1, \quad p \in N_p, r \in K_2 \tag{16}$$

$$\sum_{r\in K_2} \sum_{(i,j)\in A_2} z_{ij}^r = 1, \quad i \in N_c \tag{17}$$

The customer demands are met

$$\sum_{(j,i)\in A_2} f_{ji} - \sum_{(i,j)\in A_2} f_{ij} = d_i, \quad i \in N_c \tag{18}$$

Capacity constraints of SEV

$$f_{ij} \leq Q_2 \sum_{r\in K_2} z_{ijr}, \quad (i,j) \in A_2 \tag{19}$$

Time constraints

Total working time does not exceed ζ

$$\sum_{(i,j)\in A_1} tt_{ij}^1 x_{ij} + \eta_1 \sum_{(i,p)\in A_1} p_p x_{ip} \leq \zeta \tag{20}$$

$$t_i + tt_{i0}^2 + \eta_2 \leq \zeta + M(1 - z_{ijr}), \quad i \in N_c, j \in N_p, r \in K_2 \tag{21}$$

Subtour elimination constraints and synchronization constraints

$$t_i + \eta_1(1 - x_{ij}) + tt_{ij}^1 x_{ij} \leq t_j + M(1 - x_{ij}), \quad (i,j) \in A_1 \tag{22}$$

$$t_i + \eta_2(1 - z_{ijr}) + tt_{ij}^2 z_{ijr} \leq t_j + M(1 - z_{ijr}), \quad (i,j) \in A_2, r \in K_2 \tag{23}$$

Time window constraint

$$a_i \leq t_i \leq b_i, \quad i \in N_c \tag{24}$$

Arrival time initialization

$$t_p + tt_{pj}^2 z_{pjr} \leq t_j, \quad p \in N_p, j \in N_c, r \in K_2 \tag{25}$$

$$tt_{0j}^1 x_{0i} \leq t_i, \quad i \in N_p \tag{26}$$

4 Appendix: Notation table

Set	
$G = (N, A)$	Directed graph
$N = \{0\} \cup N_p \cup N_c \cup \{0'\}$	Set of nodes
$N_p = \{1 \dots n_p\}$	Set of parking nodes
$N_c = \{n_p+1 \dots n_p+n_c\}$	Set of customers nodes
$A = A_1 \cup A_2$	Set of arcs
A_1	The set of FEV arcs, $\{(i,j) \vert i,j \in \{0\} \cup N_p \cup \{0'\}, i \neq j\}$
A_2	The set of SEV arcs, $\{(i,j) \vert i,j \in N_p \cup N_c, i \neq j\} \setminus \{(i,j) \vert i,j \in N_p\}$
N_c	The set of customer nodes
N_p	The set of parking nodes
K_1	The set of MM
K_2	The set of SEV from one MM
Parameter	
c_{ij1}	Travel cost of arc $(i,j) \in A_1$
c_{ij2}	Travel cost of arc $(i,j) \in A_2$
p_p	Parking node $p \in N_p$ is occupied by a MM or not
d_i	Demand of customer $i \in N_c$
$dist_{ij}$	Travel distance of robot in arc $(i,j) \in A_2$
Q_0	Capacity of FEV
Q_1	Capacity of MM
Q_2	Capacity of SEV, $Q_0 \gg Q_1 \gg Q_2$
η_1, η_2	Operation time of replenishment at parking node, or service time at customer node. $\eta_1 > \eta_2$
ζ (zeta)	Length of planning horizon
$[a_i, b_i]$	Time window of customer i $\in N_c$
e	Max travel distance of robot
$tt1_{ij}$	Time to travel arc$(i,j) \in A_1$ for truck
$tt2_{ij}$	Time to travel arc$(i,j) \in A_2$ for robot
Variable	
$x_{ij} \in \{0,1\}$	$= 1$ if arc $(i,j) \in A_1$ is traveled by a FEV
$y_{ij} \in \{0,1\}$	$= 1$ if arc $(i,j) \in A_1$ is traveled by FEV with MM
$z_{ijr} \in \{0,1\}$	$= 1$ if arc $(i,j) \in A_2$ is used by SEV $r-th \in K_2$ dispatched from a mobile microhub
$w_p \in \mathbb{R}^+$	Amount of freight transported from depot to MM located in $p \in N_p$
$f_{ij} \in \mathbb{R}^+$	Freight flow of arc $(i,j) \in A_2$
t_i	Arrival time of SEV at customer $i \in N_c$ or the arrival time of FEV at parking node $i \in N_p$