PhEMS4VN: Pheromone Emergency Message System for Vehicular Networks

Set, Tuple, Interval or variable	Elements	Description	Initial index or element	Representative indexes or elements	Final index or element
ME	$\{me_1, me_2, \ldots, me_n\}$	Set of mobile entities: representative mobile entity me_k	1	i, j, k	n
FE	$\{fe_1, fe_2, \ldots, fe_m\}$	Set of fixed entities: representative fixed entity: fe_g	1	g, h	m
$re(fe_g)$	$\{a, b, \ldots, d\}$	Outbound exits of region in azimuth degrees defined for each fixed entity g, where $a = 0, b = 90$, …, equivalent to north, east,…, respectively	a	$a, b, \ldots$	d
$ri(fe_g)$	$\{a', b', \ldots, d'\}$	Inbound inlets of region in azimuth degrees defined for each fixed entity g, where $a' = 0, b' = 90$, …, equivalent to north, east,…, respectively	a'	$a', b', \ldots$	d'
INC_k	$\{inc_k^1, inc_k^2, \ldots, inc_k^r\}$	Local set of all (k, r) incidents provoked by mobile entity k, where k denotes entity identifier, and r denotes the number of incident	1	p, q	r
inc_k^p	$(k, p, (x_k, y_k, t_\alpha^{k,p}))$	Spatio-temporal coordinates of location and initial time α of incident (k, p) provoked by mobile entity k	α		
Δ_k^p	$[t_\alpha^{k,p}, t_\omega^{k,p}]$	Interval with final time ω of incident (k, p), only known when finished	$t_\alpha^{k,p}$		$t_\omega^{k,p}$
$mess_k(inc_k^p)$	$\left(k, p, \left(x_k, y_k, \lambda t_\alpha^{k,p}\right), Stt\right)$	Message containing spatio-temporal coordinates of incident (k, p), provoked and segregated by mobile entity k; where $Stt = 0$ if initial segregation, $Stt = 1$ if subsequent segregation, or $Stt = 2$ if incident is external to mobile entity k			
$\lambda t_\beta^{g,k,p}$		Periodical physical time(s) when $mess_k(inc_k^p)$ is acquired by fixed entity g and related pheromone's lifetime begins or is extended by reaffirmation	1	λ	$\max(\lambda)$
$\lambda t_\gamma^{g,k,p}$	$= \lambda_\beta^{g,k,p} + \delta t$	Periodical physical time(s) when pheromone relative to incident (k, p) is going to expire after being started or restarted by fixed entity g at time $\lambda t_\beta^{k,p}$	1	λ	$\max(\lambda)$
$\phi_g^{k,p}(fe_g)$	$(g, inc_k^p, \mathrm{I}(\phi_g^{k,p}))$	Pheromone data structure over indicated region of fixed entity			
$\Delta\phi_g^{k,p}(fe_g)$	$[1t_\beta^{k,p}, \lambda t_\gamma^{k,p}]$	Overall pheromone's lifetime relative to incident (k, p) on fixed entity g	$1t_\beta^{k,p}$		$\lambda t_\gamma^{k,p}$
$timer\_\phi(g, k, p)$	$(inc_k^p, \lambda t_\beta^{g,k,p}, \lambda t_\gamma^{g,k,p}, value)$	Physical countdown timer that extends lifetime of pheromone on fixed entity g and relative to incident (k, p)	100%		0%
$\mathrm{I}(\phi_g^{k,p})$	$(\iota_a = 0..1, \iota_b = 0..1, \ldots)$	Intensity on subregions $a, b, \ldots$ computed with $timer\_\phi(g, k, p)$, with current time value as factor, where each intensity value is a real number in $[0,1]$	0		1
$mess_g(\phi_g^{k,p})$	$(g, inc_k^p, (\iota_a, \iota_b, ..), timer(g, k, p))$	Pheromone on fixed entity g of incident (k, p) provoked by mobile entity k that contains intensities in respective subregions	1		

Table 1: Used notation in system model definition

PhEMS4VN: Pheromone Emergency Message System for Vehicular Networks

Internal events mobile processes mp_k	Description
$Crt(inc_k^p)$	Creation of incident
$MGen(mess_k(inc_k^p))$	Generate incident message to be segregated
$MSt(inc_k^p)$	Countdown timer start or restart for indicated incident
$Mdec(mess_h(\phi_g^{k,p}))$	Intensities decapsulate from consumed pheromone
$MEn(inc_k^p)$	End of countdown timer for indicated incident
$MTrm(inc_k^p)$	Termination of indicated incident

External events mobile processes mp_k	Description
$Seg(mess_k\ (inc_k^p))$	Segregate message of incident
$Con(\phi_g^{k,p})$	Consume pheromone
$Act(\phi_g^{k,p})$	Action after consuming pheromone

Table 2: Events for mobile entities

Internal events fixed processes fp_g	Description
$FDec(mess_k(inc_k^p))$	Decapsulate incident from message acquired
$FGen(\phi_g^{k,p})$	Generate pheromone
$FSt(timer(g,k,p))$	Countdown timer start or restart for indicated pheromone
$Upd(\phi_g^{k,p})$	Update intensity in pheromone with timer when query detected
$FEn(timer(g,k,p))$	Countdown timer end for indicated pheromone
$FTrm(\phi_g^{k,p})$	Termination of indicated pheromone

External events fixed processes fp_g	Description
$Acq(mess_k(inc_k^p))$	Acquisition of incident message
$Ntf(mess_g(\phi_g^{k,p}))$	Notify pheromone

Table 3: Events for fixed entities

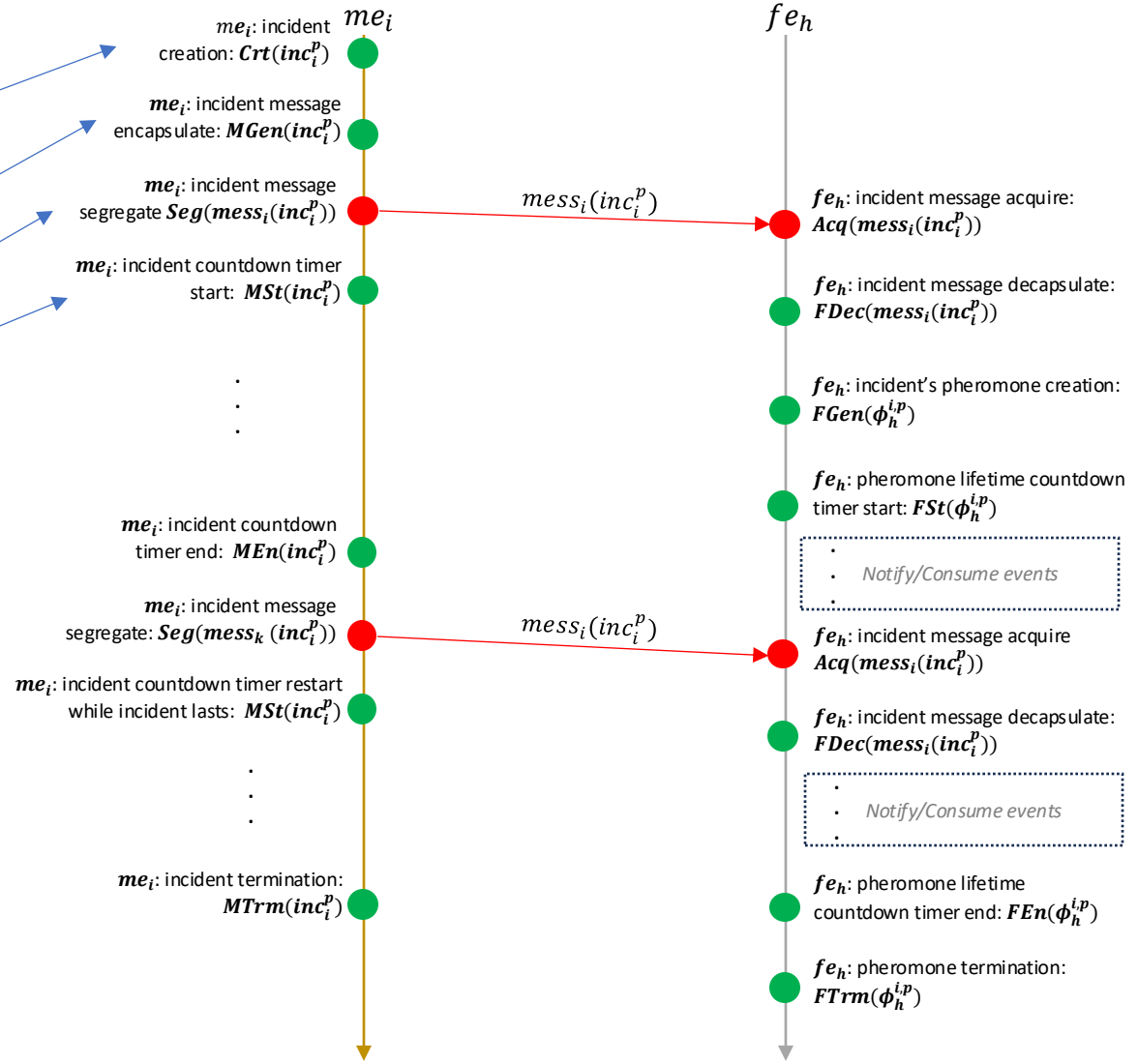
PhEMS4VN: Pheromone Emergency Message System for Vehicular Networks

Algorithm 1: incident creation and message incident segregation EMS by mobile entity me_i over fixed entity fe_h:

Input: $\boldsymbol{abnormal\ stop}$ *of* me_i; *previous value of* $\boldsymbol{p}$

Output: $\boldsymbol{mess(i,p)} = \left(\boldsymbol{i,p,}\left(\boldsymbol{x_i, y_i, t_\alpha^{i,p}}\right), \boldsymbol{Act}\right)$ *segregated on* fe_h *at least once*

1. **if** (*abnormal stop detected*) **then**
2. $p \leftarrow p + 1$
3. $x_i, y_i, t_\alpha^{i,p} \leftarrow (long, lat, time)$
4. $inc(i,p) \leftarrow i, p, (x_i, y_i, t_\alpha^{i,p})$ //*event Crt*
5. $failure \leftarrow 1$
6. $Act \leftarrow 0$
7. $mess(i,p) \leftarrow (i, p, (x_i, y_i, t_\alpha^{i,p}), Act)$ //*event MGen*
8. **while** $(failure)$ && $(countdown\_timer > 0)$
9. **unicastcast** $mess(i,p)$ *on* fe_h //*event Seg*
10. **start** *countdown_timer* //*event MSt*
11. $Act \leftarrow 1$
12. **if** (*abnormal stop ended*) **then**
13. $failure \leftarrow 0$
14. $t_\omega^{i,p} \leftarrow t_i$
15. **end**
16. **else**
17. **if** $(countdown\_timer == 0)$ **then**
18. **reset** $(countdown\_timer)$ //*event MSt*
19. **end**
20. **else**
21. *do nothing*
22. **end**
23. **end**
24. **else**
25. **end**
26. **else**
27. *do nothing*
28. **end**



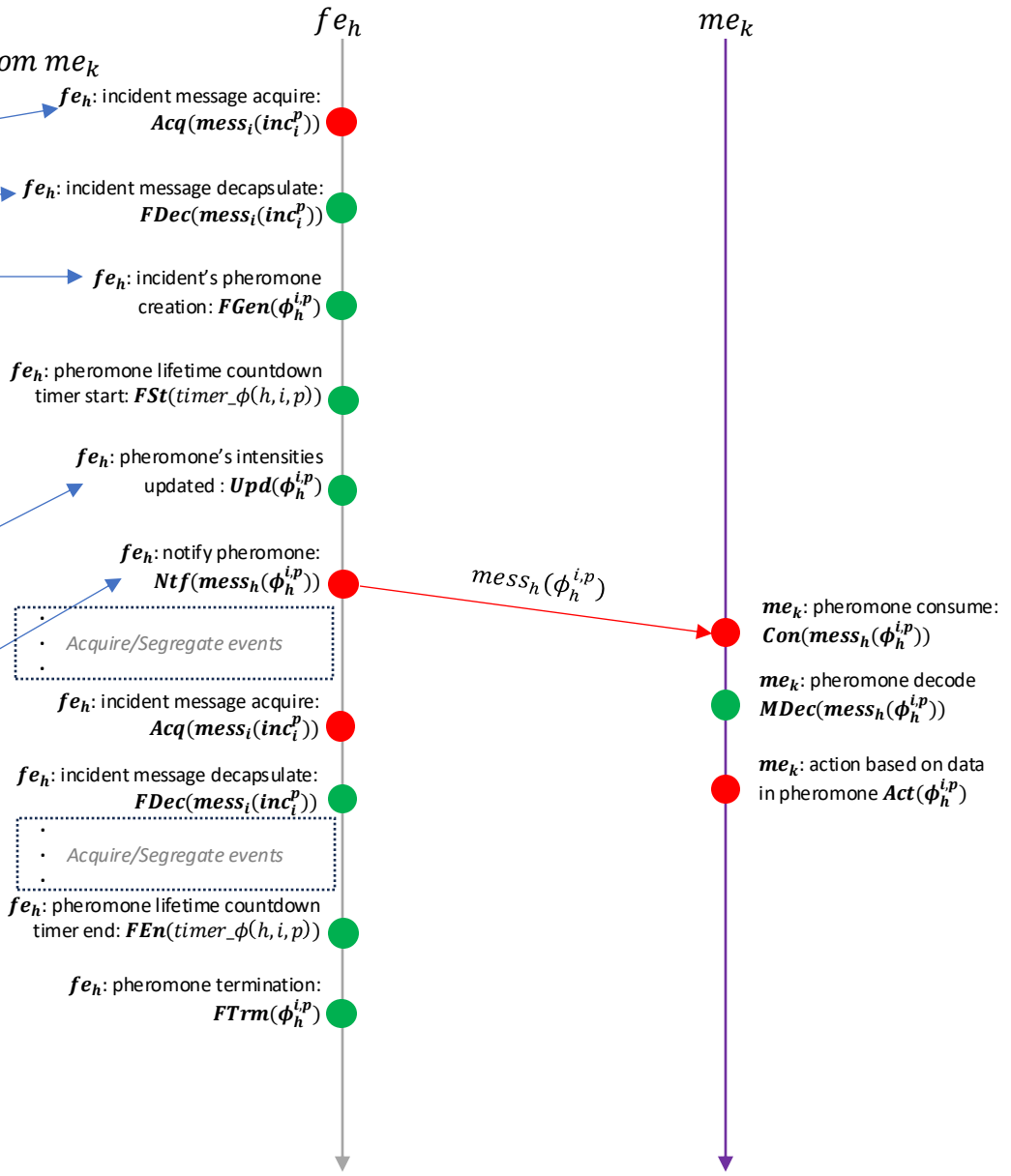
PhEMS4VN: Pheromone Emergency Message System for Vehicular Networks

Algorithm 2: incident message acquisition on fixed entity fe_h from me_i and creation and notification of pheromone on mobile entity me_k:

Input: $\boldsymbol{mess_i(i,p) = \left(i,p,\left(x_i,y_i,t_\alpha^{i,p}\right),Act\right)}$ *in* fe_h *acquired from* me_i; $\boldsymbol{Qry(x_k,y_k,t_k)}$ *received from* me_k

Output: $\boldsymbol{mess_h(\phi_h^{i,p}) = (h, inc_p^i, (\iota_a,\iota_b,\dots), timer(h,i,p))}$ *notified on* me_k

1. **receive** $mess(i,p) = (i,p,(x_i,y_i,t_\alpha^{i,p}),Act)$ *from* me_i *//event Acq*
2. $i,p,(x_i,y_i,t_\alpha^{i,p}),Stt \leftarrow mess(i,p)$ *//event FDec*
3. $\phi_h^{i,p}(fe_h) \leftarrow (h, inc_i^p, \mathrm{I}(\phi_h^{i,p}))$
4. **if** $(Stt == 0)$ **then**
5. $\boldsymbol{\lambda \leftarrow 0}$
6. **start** $timer\_\phi(h,i,p)$ *on* 100% *//event FSt*
7. **generate** *random numbers in* $[0,0.1]$ *for all exits intensities* $\iota_b,\iota_c,\dots$ *except* ι_a *corresponding to* (x_i,y_i)
6. **end**
7. **else if** $(Stt == 1)$ **then**
8. $\boldsymbol{\lambda \leftarrow \lambda + 1}$
9. **reset** $timer\_\phi(h,i,p)$ *on* 100% *//event FSt*
10. **end**
11. **else if** $(Stt == 2)$ **then**
12. **if** $((x_k,y_k)$ **in subregion a with some** ϵ_x **and** $\epsilon_y)$ **then**
13. **start** $timer\_\phi(h,i,p) \leftarrow timer\_\phi(h,i,p) + weight\%$ *//events FSt partial*
14. **end**
15. **end**
16. **while** $(timer\_\phi(h,i,p) > 0)$
17. *update* $\mathrm{I}(\phi_h^{i,p})$ *//event Upd*
18. $mess_h(\phi_h^{i,p}) \leftarrow (h, inc_i^p, (\iota_a,\iota_b,..), timer(h,i,p))$
19. **broadcast** $mess_h(\phi_h^{i,p})$ *on* me_k *//event Ntf*
20. **if** *(receive* $mess_i(i,p)$*)*
21. **start** $timer\_\phi(h,i,p)$ *on* 100%
22. **end**
23. **else**
24. **do** *nothing*
25. **end**



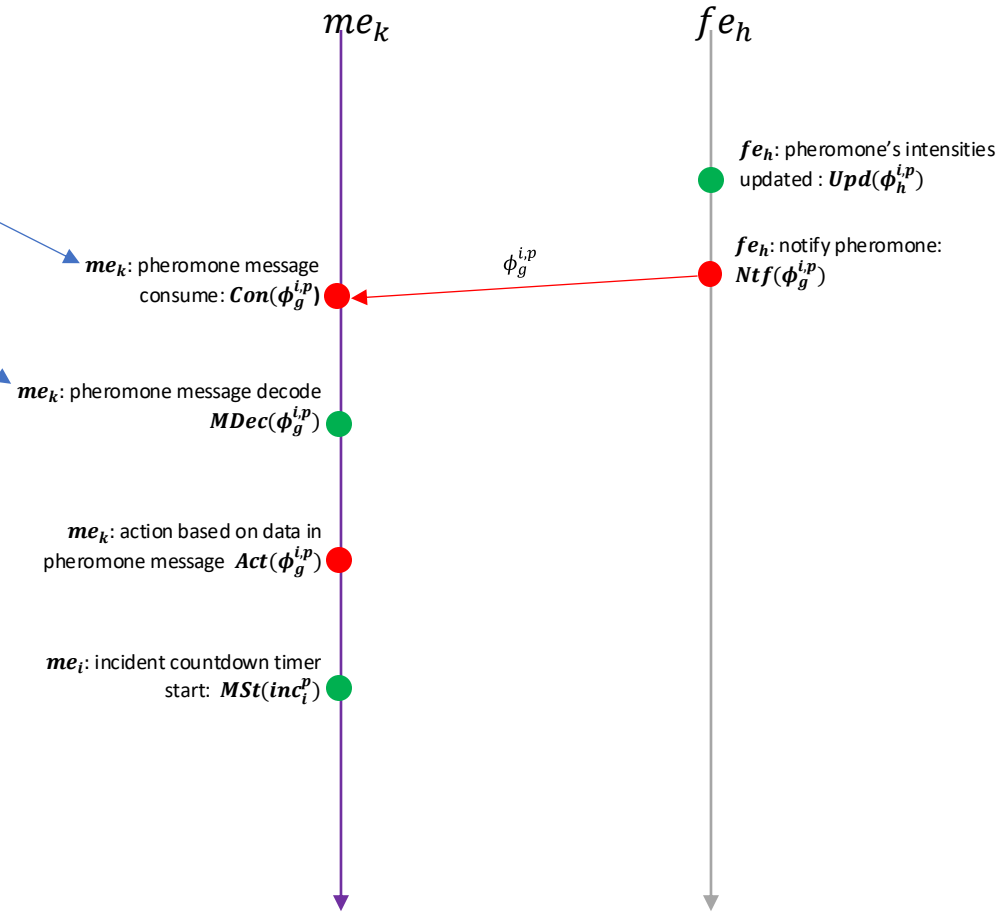
PhEMS4VN: Pheromone Emergency Message System for Vehicular Networks

Algorithm 3: pheromone message consumption on mobile entity me_k from fixed entity fe_h:

Input: $\boldsymbol{mess_h(\phi_h^{i,p}) = \left(h, inc_p^i, (\iota_a, \iota_b, \dots), timer(h,i,p)\right)}$ *consumed on* me_k *from* fe_h

Output: ***decision based on data from consumed pheromone message***

1. ***receive*** $mess_h(\phi_h^{i,p}) = \left(h, inc_p^i, (\iota_a, \iota_b, \dots), timer(h,i,p)\right)$ *from* fe_h *//event Con*
2. $h, inc_i^p, timer\_\phi(h,k,p), (\iota_a, \iota_b, \dots) \leftarrow \phi(h,i,p)$ *//event MDec*
3. ***if*** $\left(any\ \iota_a, \iota_b, \iota_c, \dots correspond\ to\ inc_i^p\right)$ && $\left(xing\left(me_k, fe_h, \phi_h^{i,p}(fe_h)\right)\right)$ ***then***
4. ***if*** $(((\iota_a > thld)$ && $(a\ in\ route_k))$ || $((\iota_b > thld)$ && $(b\ in\ route_k)$ || $\dots)$ ***then***
5. ***do*** $re-route$ *//event Act*
6. ***end***
7. ***else***
8. ***do*** $nothing$
9. ***end***
10. ***end***
11. ***start*** $countdown\_timer\ with\ timer\_\phi(h,i,p).value\ with\ consumed\ value$



PhEMS4VN: Pheromone Emergency Message System for Vehicular Networks

Interaction between me_j and fe_h'

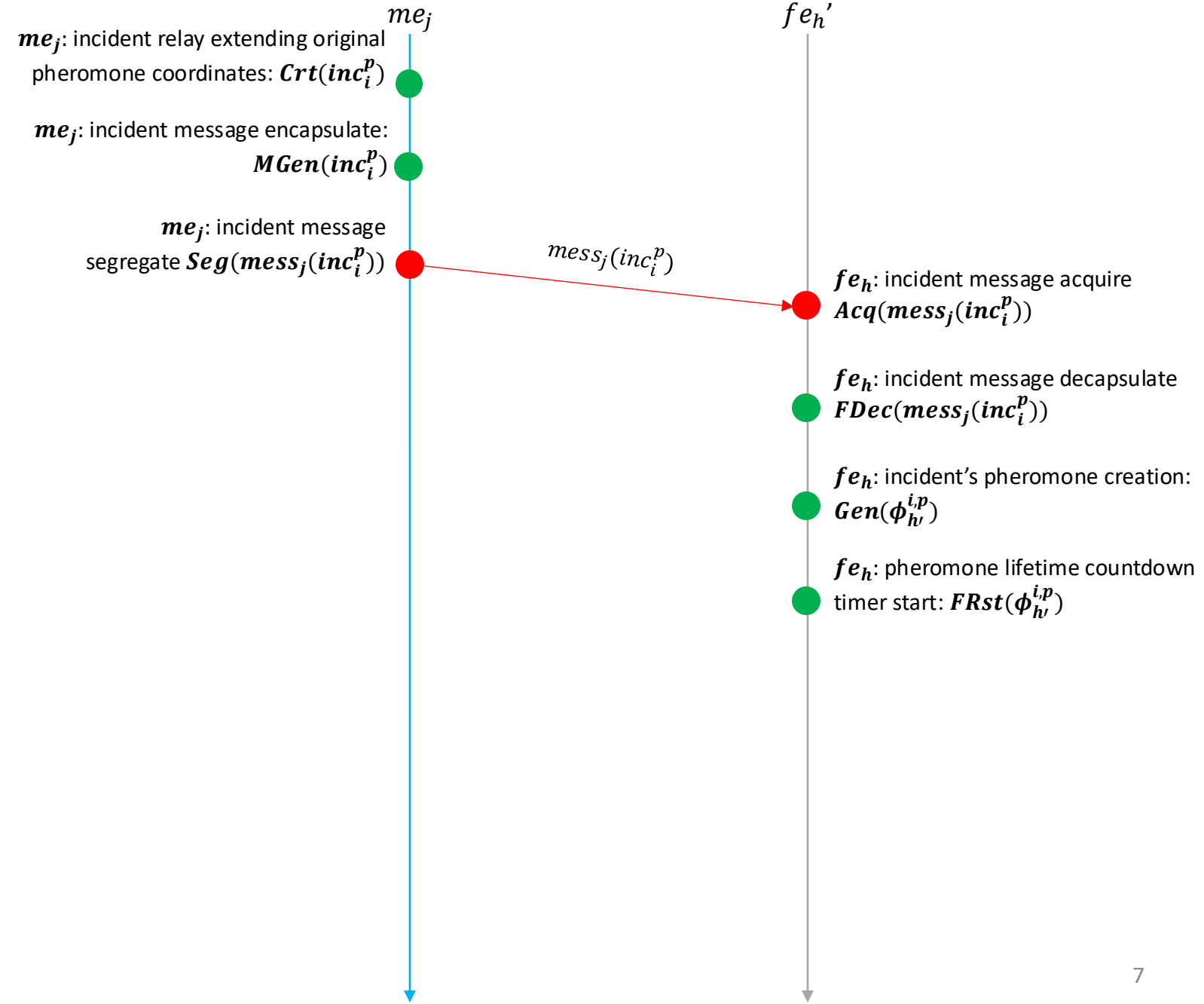

Internal event


External event

me_j: detects incident and segregates one incident message on fe_h'

fe_h': acquires incident message, creates pheromone of extra-regional incident

Constraints:
$uniq(me_j, fe_h') = 1$



PhEMS4VN: Pheromone Emergency Message System for Vehicular Networks

Algorithm 4: incident relay and segregation of incident message by mobile entity me_j on fixed entity fe_h':

Input: $\boldsymbol{\phi}(\boldsymbol{h},\boldsymbol{i},\boldsymbol{p}) = (\boldsymbol{h}, \boldsymbol{inc_i^p}, \boldsymbol{timer}(\boldsymbol{h},\boldsymbol{i},\boldsymbol{p}), (\boldsymbol{\iota_a} \approx \mathbf{1}, \boldsymbol{\iota} \cong \mathbf{0}, \ldots))$, *i.e., knowledge of* incident *of* me_i *known by* me_j *through* fe_h; *previous value of* $\boldsymbol{q}$

Output: $\boldsymbol{mess}(\boldsymbol{j},\boldsymbol{q}) = (j, q, (x_i, y_i, t_\alpha^{j,q}), Act)$ *segregated on* fe_h *once and only once*

1. ***if*** $(countdown\_timer > 0)$ && $(x_k, y_k \in re(fe_h'))$ && $(re(fe_h) \cap ri(fe_h') \neq \emptyset)$ ***then***
2. $\quad q \leftarrow q + 1$
3. $\quad (x_h, y_h), t_\alpha^{j,q} \leftarrow (x_h + \epsilon\_x_h, y_h + \epsilon\_y_h, t_j)$ $\quad //event\ Crt\ \_$
   $\quad for\ x_h, y_h\ plus\ displacement\ from\ me_j\ time$
3. $\quad Stt \leftarrow 2$
4. $\quad mess(j,q) \leftarrow (j, q, (x_i, y_i, t_\alpha^{j,q}), Stt)$ $\quad //event\ MGen$
5. $\quad$ ***unicast*** $mess(j,q)$ *on* $fe_h{}'$ $\quad //event\ Seg$
6. ***end***
7. ***else***
8. $\quad$ ***do*** *nothing*
9. ***end***